SCIENCE LECTURES FOR THE PEOPLE.

SCIENCE LECTURES

DELIVERED IN MANCHESTER,

1875-76.

SEVENTH AND EIGHTH SERIES.

MANCHESTER:
JOHN HEYWOOD, 141 AND 143, DEANSGATE.
LONDON:
JOHN HEYWOOD, 18, PATERNOSTER SQUARE, E.C.; SIMPKIN, MARSHALL, & CO.

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ARCTIC DISCOVERIES.

WITH SPECIAL REFERENCE TO THE PRESENT EXPEDITION.

A LECTURE delivered in the Hulme Town Hall, Manchester, on Tuesday, October 26th, 1875.

BY CAPTAIN J. E. DAVIS, R.N., F.R.G.S.

TO attempt to give an outline of Arctic exploration generally, within the limit of time assigned to me, is out of the question. I therefore propose to confine myself to a very brief sketch of those voyages that have been directed to the attempt to reach the Pole itself, prefacing the sketch of those voyages by equally brief remarks on the different routes. [Captain Davis here explained the numerous charts, maps, &c.; with which his lecture was illustrated.]

The extent of our knowledge of those vast regions lying between Greenland and Behring Strait, about half a century ago, viz., in 1818, was confined to the sea coast at the entrance of the Coppermine and Mackenzie rivers, and the coast-line from Behring Strait to Icy Cape. All the coast between those distant points, and nearly all the land north of it, is due to the discoveries of Englishmen since that date. Surely we may be justly proud of these peaceful honours won by our countrymen.

It is still a moot question as to whom the discovery of the North-West Passage is due, whether to Franklin or M'Clure. I am disposed so to divide the honour as to give the priority of discovery to Sir John Franklin, whilst to Sir Robert M'Clure is undoubtedly due the honour of being the first who ever entered Behring Strait and came out by Davis Strait, although a part of that distance, connecting his discoveries with those of Parry, was not accomplished by ship or boat, but by travelling over the ice.

There are four routes by which an approach to the Pole may be considered feasible.

(1.) By Behring Strait. This route I shall at once dismiss, as being the least feasible of the four, and one, which although often proposed, has never been attempted.

(2) By the East coast of Greenland. The prospect of success in attaining a high latitude by this route is extremely problematical, the continual drift of ice generally choking the passage between Spitzbergen and the main, and always setting to the southward renders the chances of working against the stream through the ice small, still it is just possible that lanes of water may be found in favourable seasons within the ice, and even eddies of the main stream setting in the opposite direction, through which a small steamer, by watching opportunities, might work her way north, but as remarked, success would be extremely problematical.

(3) The third route is that between Spitzbergen and Novaya Zemlya; but we should more properly describe it now as between Spitzbergen and Franz Joseph Land. Here there is, I believe, far more chance of success than either by Behring Strait or the east coast of Greenland, but all progress in the Polar regions is one of chances; still by observing previous seasons in the matter of the quantity of the moving or travellimg ice, even these chances may, in some degree, be calculated, and one season pronounced far more promising than another: thus, the one just past was considered a favourable one, for the quantity of ice that drifted south last year was exceptionally great. In May, June, July, and August its average drift was fully fourteen miles a day. In the two months previous to those it must have been drifting at double that rate. Captain David Gray, an experienced whaling captain of Peterhead, told me that he considered that nearly the whole of the ice had been driven out of the Arctic basin last summer, and he himself, in latitude 80°, saw no ice, and there was a dark water sky rose northward.

(4) The fourth route is that by Baffin Bay, and here it would be possible to start half a dozen fresh or branch routes. Each strait between those islands may be considered a route to the Pole; but the particular route of these is that by Smith Sound, or between the west coast of the great continent of Greenland and the lands or islands that lie west of it. It cannot be denied that this route has advantages which the others have not, all of which have been considered in determining the path of the present expedition. For instance, there is the encouragement derived from the American expeditions, for although Kane and Hayes did not attain a high latitude, the Polaris did. It is also considered more favourable for sledging; and one axiom in Arctic exploration is in support of it, viz., "never turn a corner if you can help it;" for you see that Smith Sound is nearly

a straight road from Davis Strait and Baffin Bay. This axiom is, however, equally applicable to the Spitzbergen route, but that is essentially a ship route, while that by Smith Sound is considered a sledge route.

I will now glance at the attempts that have been made to reach the Pole by these three routes, consecutively.

East Greenland Route.—The first voyage made to reach the Pole was by Henry Hudson in 1607. As attempts had been made to reach India and Cathay both by the North-west and North-east Passages without success, it was determined by the Muscovy Company of Merchants to cut the Gordian knot by sailing directly across the Pole; and Henry Hudson, an experienced seaman and navigator, was selected to conduct the expedition, and I beg you will note the means placed at his command, compared with the expedition now on its way for the same purpose. A vessel of 80 tons was allotted to him, and in that, with a crew of ten men and a boy, Hudson left Gravesend on May Day of 1607, to make his way to the North Pole! He made the coast of Greenland in latitude about 69°. Ice lay in with the shore, but he worked his little craft to the northward to latitude 73°, and to the land then seen he gave the name of "Hold with Hope." As he found he could not proceed along the Greenland coast by reason of the ice, he stood across to Spitzbergen to 77° N., where he saw the coast and the ice lying thick upon it. With much difficulty he got round on the north coast, and was doubtless within sight of Seven Islands; but after many ineffectual and gallant efforts to get North, and being in want of many necessaries, he was obliged to bear up for England, where he arrived on the 15th September. This expedition, though small, was one of considerable importance, as it made us acquainted with the north and north-west parts of Spitzbergen. Hudson was the first who observed with the dipping needle.

Keeping to the East Greenland route, we come to the two German expeditions of 1868 and 1869; and although the means by which these gallant Germans sought to reach the Pole were ludicrously small, it is a proof of the spirit which animated the promoters of the undertaking. At the same time it is a proof of their ignorance in sending expeditions totally inadequate for what they were expected to accomplish; thus courting failure, although they deserved better success than attended them. The first expedition, under Captain Koldeway, consisted of a vessel of the same size as its predecessor on that route—80 tons—the Germania,

and the same number of men; and, strange to say, they did much the same as Hudson did, and returned to Bergen without having accomplished much.

Nothing daunted by the non-success of the voyage, great exertions were made to get a second and more efficient expedition afloat, and with success. It consisted of a small steam vessel of 143 tons, strengthened and re-named the Germania, whilst the Germania of the previous voyage was re-named the Hansa. Captain Koldeway again commanded, having a brave and active second in Captain Hagemann in the Hansa. They left Bremerhaven on the 15th June, 1869, and made Jan Mayen, then for the edge of the ice off the Greenland coast in latitude 74¾°. Here they experienced dense fogs, in one of which, owing to a mistake in a signal, they parted company, never to meet again. The Hansa soon got hemmed in by ice, and was lifted seventeen feet by the bow. In such a position the probability of the vessel breaking-up was so imminent that she had to be abandoned for a house built of stones, coal, and snow on the floe, and shortly after this was accomplished the Hansa slipped off and went down. After a winter of incredible suffering, during which they were set down along the Greenland coast, they quitted their icy prison in the boats, and, safely rounding Cape Farewell, reached Fredericksthal, from whence they were transferred to their native country. The Germania was more fortunate than her consort. She got to a harbour from whence sledge journeys were made in various directions. A magnificent fiord was explored in latitude 73°, which was named "Kaiser Franz Joseph." The Germania got clear of the Greenland coast on the 17th August, 1870, and reached Bremerhaven on the 11th of the following month.

Spitzbergen Route.—In 1773 two bomb vessels, the Racehorse and Carcase, selected for their great strength and capacity for stowage, were fitted up to go to the Pole by the Spitzbergen route, under the command of the Hon. Captain Phipps, afterwards Lord Mulgrave. They reached Spitzbergen, proceeding along the west shore, and, after much exertion, reached lat. 80° 36′ N., and returned safely to England. It may be worthy of mention that a lad served in this expedition who was destined to become a great hero, and rise to the highest honour in the service to which he belonged. This was Nelson.

The *Dorothea* and *Trent*, Captain Buchan and Lieutenant Commanding John Franklin, left England in May, 1818, and reached Spitzbergen on the 7th June. With all their exertions

they only reached lat. 80° 34′, and after being nearly wrecked in a heavy gale, in which their ships received such damage as to prevent their attempting to take the ice again, they returned to England.

Parry's Voyage.—After four voyages to the Polar regions, in attempting to make the North-west Passage, Captain Parry was willing to enter on yet another voyage to attempt to reach the Pole by the Spitzbergen route; and as it was considered impracticable to effect it with ships, it was proposed to try to do so by means of sledge boats, to be drawn over the ice, and sailed or rowed through the water, as opportunity offered. The Hecla was the vessel employed on this occasion, and early in 1827 she left England and reached Spitzbergen in June, when they started in two boats, Captain Parry commanding one, and Lieutenant J. Clark Ross the other, taking with them seventy-one days' provisions.

At first the prospect to the northward was favourable, and they experienced no difficulty until they reached lat. 81° 13′, when they were stopped by close ice, and they commenced travelling over it. To avoid the intense glare of the sun from the snow during the day, when the sun's altitude was high, and which produced snow blindness, they travelled by night and slept by day. Instead of finding the ice smooth, as they expected, it was rough, ragged, and loose, and their work was extremely laborious. On the 30th June they found that they had made only eight miles of northing in five days. On the 12th July they were in lat 82° 14′; the next day 82° 17′; such was the slow progress made owing to the continued set to the southward. On the 20th they found they had only made five miles since the 17th. The men worked cheerfully, as they knew that a reward of £1,000 was to be gained on reaching the 83rd degree, and as they were kept in ignorance of the southerly set, the poor fellows could not well understand why they did not reach the goal. At midnight on the 22nd they reached the highest point that before or since has ever been reached—82° 45′, and then finding they were daily losing ground instead of gaining, they were reluctantly obliged to give it up and return to their ship, reaching her after an absence of 61 days. [The lecturer here paid a high tribute to the character of the late Sir Edward Parry, which he characterized as being that of a true seaman, a gentleman, and a Christian.]

Since Parry's voyage a number have been made in the same direction, but none of them reached within a degree of Parry. The Swedes and Norwegians have done good service here;

also our own countrymen, Mr. Lamont and Leigh Smith. In 1871 Lieuts. Payer and Weyprecht, in a small vessel of seventy tons, with a crew of eight men, attempted to reach Gilliesland by following, what is considered to be, the course of the Gulf Stream, hoping to find a passage clear of ice. They reached lat. 78° 41′ N., and found a gradually decreasing depth of water, and from numerous bear tracks on the ice they supposed that land was not far off. Any argument to the effect that the Pole is not to be approached in that direction, from the failure of all these vessels, is not sound; and until such an expedition as is now on its way to the North Pole is turned back in this direction, I will believe it is practicable.

Austrian Expedition.—The fact that Austria had never entered the list of Polar discovery renders the expedition of the Tegethoff remarkable in one sense, and the difference in the mode of proceeding renders it equally remarkable in another; for whilst the navigators of all others did their utmost to take their ships to their discoveries, that of the Austrians took her navigators to theirs. The Tegethoff, a screw steamer of 220 tons, commanded by Capt. Weyprecht, left Bremerhaven on the 13th June, 1872. Weyprecht was accompanied by Lieut. Payer, who had served in the German expedition on the East Greenland coast. The Tegethoff got to Nova Zembla, and on the 21st August, the ice appearing broken, they tried their luck, but got encompassed with ice the same night, were frozen up, and remained so for two long and cheerless years. The account of this voyage is most interesting. Many a time were they called, in the midst of the long Polar night of 109 days, to save themselves, when by pressure of the ice they thought their ship must founder, and this with a minimum temperature of 51 degrees, or 83 degrees below the freezing point. The ice first bore them to the north-east and then to the north-west. On the last day of August they were surprised by the sudden appearance of mountainous land about fourteen miles to the north. Payer says: "At that moment all our past anxieties were forgotten; impulsively we hastened towards the land, fully aware that we should not be able to get further than the edge of our floe. For months we were doomed to suffer the torments of Tantalus. Close to us, and in fact almost within reach, was a new Polar land, rich with the promise of discoveries, and yet drifting as we were at the mercy of the winds, and surrounded by open fissures, we were unable to get any nearer to it." At the end of October the ship was borne

within three miles of one of the islands, and making their way over the hummocky ice, they reached the land in latitude 79° 54′.

The joy of having discovered new land buoyed them up through the second long and dreary winter; and on the 10th March last year, Payer started on their first sledge expedition, but the cold was intense; on one occasion it reached to 58° (90 degrees of frost), and they suffered much. On a second expedition they were enabled to map the country, and on the 26th March they reached latitude 81° 57′, their highest point. A third sledge journey was made, and then, having nailed the colours of their country to the mast of their ship, they abandoned her, and proceeded south with their boats on sledges; and after innumerable difficulties, and with incessant labour, they reached Nova Zembla, from whence a Russian vessel conveyed them to Norway.

Smith Sound Route.—Although Dr. Kane's voyage in the little brig Advance, in 1853, was not one made with the object of reaching the Pole, but was literally one in search of Franklin, it may be mentioned in connection with one fact bearing on the progress and prospects of the present expedition, viz.: the alleged discovery of an open Polar Sea. Dr. Kane himself made no such discovery, but he sent his steward, a man named Morton, who from a cliff in latitude 81° 22′ said he saw an open Polar Sea, with an iceless horizon, and a heavy swell rolling in. Now I can only sum up this important discovery in the very words I did many years ago at the Royal Geographical Society—"Morton was ordered to discover an open Polar Sea, and he obeyed his orders." If he saw water at all it was but a channel opened by the current in the height of summer.

Dr. Isaac J. Hayes, in a schooner of 133 tons, on reaching Smith Sound, made every effort to get over on the west shore, but pack ice obstructed him. He succeeded in getting into a snug harbour in latitude 78° 17′, where he wintered; and the next spring he made his way by sledge to the west shore. Such were the difficulties he encountered that he was 31 days in getting a distance of 81 miles. He got as far as the 80°, when his men broke down. He, however, pressed on, and finally reached a latitude of 81° 35′, from whence he had the gratification of having the open Polar Sea before him. Dr. Hayes was justly proud of his discovery, and of having reached the most northern land the foot of civilised man had ever trod. Dr. Hayes succeeded in regaining his vessel after an absence of 61 days; and on the 11th July, 1861, left his harbour and returned to the United States.

Voyage of the Polaris.—Captain Hall, a citizen of the United States, who had spent many years in the Arctic regions in search of Sir John Franklin, and who in 1869 had just returned from a five years' residence in the north, living with the Esquimaux, soon agitated for another expedition; and after much trouble a river gunboat of 387 tons was allotted to him by the Navy Department of the United States, and christened, or rather re-christened, the Polaris. As Hall was no seaman, and was even ignorant of nautical astronomy, a whaling captain—Buddington—was appointed to accompany him; and Dr. Bessels, who had served in one of the German arctic expeditions, accompanied him as naturalist and surgeon.

Hall was to follow in the steps of Kane and Hayes. He sailed in 1871, completing provisions for two and a half years, at Disco; left the most northern Danish settlement in August, pushed up Smith Sound and was most successful. He took the Polaris 250 miles up the strait, and reached a higher latitude than had ever before been attained by any *ship*, and within 30 miles of Parry's farthest; the latitude he attained being 82° 16′. I beg you to notice that I have three times used the word "farthest," but each time with a different meaning. Parry reached the farthest north latitude that ever man reached in a boat; Hayes reached the farthest latitude upon the solid earth; and the Polaris reached the highest latitude that ever a ship attained. You see there are three farthests, but all different.

At this extreme latitude Hall's vessel was beset, but a powerful vessel might have forced her way through the ice then seen; moreover, a deep water horizon was seen to the north-east, proving that had it not been for the weak steam power of the vessel she might have proceeded much further—so nearly were our Polar honours of getting furthest north, wrested from us. The extreme northern point was reached by the Polaris on the 24th August, and, strange to say, this high latitude was reached without any check or obstacle of any kind.

The winter quarters were in Thank God Bay, in latitude 81° 38′, which the Polaris reached on the 5th September. Three weeks after getting into this harbour, Captain Hall started with a party overland, but he did not get farther than 82°. On his return he was taken ill, became partially paralysed, and died on the 8th November, leaving to others the honours so justly his due.

The year the Polaris reached so high a latitude must have been an unusually mild one, for at Thank God Harbour the ground was free from snow, a creeping herbage covered the

ground, on which numerous herds of musk oxen found pasture, and rabbits and lemmings abounded. Wild flowers were brilliant, and large flocks of birds passed northwards, while traces of Esquimaux were found.

On the death of Captain Hall the direction of the expedition devolved on Captain Buddington, who seems to have had no spirit for the enterprise from the beginning, and he resolved to prosecute the voyage no further, but to return as quickly as possible. He did not even form sledge parties in the spring, which might greatly have added to the interest of the voyage. On the 12th August, 1872, the Polaris was again free. When she got as far south as 80° she was beset with ice, and drifted out through Smith Sound into Baffin Bay. In latitude 77½° the ship was so severely nipped, that provisions and boats were got out on the ice ready for deserting her; but suddenly the ice broke up and the ship flew off before a gale of wind, leaving nineteen men, women, and children on the floe, with the boats and provisions. The Polaris was found to have sprung a leak, and the water was rising in the hold to such an extent that Captain Buddington ran his ship on shore near Lyttleton Island. Here they wintered, and having built boats from the timber and planking of the ship, they all embarked on 3rd June, 1873, and were picked up by an English whaler off Cape York. The unfortunates who were left on the floe drifted down Baffin Bay, and were eventually picked up in latitude 53½°, near Wolf Island.

Of the crew that accompanied poor Hall only about nine were native-born Americans. The expedition seems to have been badly organised, and there was a want of discipline and order in the whole conduct of the voyage, which proves that those who embark in such undertakings require to be under good law and discipline. The great success that attended the Polaris voyage was not attributable in the least to order; but the non-following up of that success may be fully attributed to a want of it. Permit me to pay a tribute to Dr. Bessels, a German, who showed himself throughout the voyage to be a man of pluck and spirit and a truly scientific observer. I fear if the whole crew of the Polaris had been animated by the same spirit as Dr. Bessels, we should have had no need of sending our own expedition to reach the North Pole.

THE PRESENT ARCTIC EXPEDITION.

As is now well known, the two ships selected for Arctic service were the *Alert*, one of Her Majesty's ships of between seven and

eight hundred tons, and the *Discovery*, formerly the Bloodhound, a whaler of nearly six hundred tons, both vessels having steam power.

Captain George S. Nares, who recently commanded the Challenger in her deep-sea exploring expedition, commands the expedition in the larger vessel, and Captain Stevenson is second in command.

A large number of astronomical and other instruments are on board, and every device that human ingenuity can suggest to help them in their great work has been executed, and nothing that forethought and money can procure is wanting. In point of fact, on these two ships, their fittings and equipments of all kinds, the information derived from a century's experience of Arctic navigation has been brought to bear, and it is not mere assertion to state, that never did an expedition leave our shores more replete in every particular for the service intended, than the Alert and Discovery. To describe the mode of strengthening the ships to withstand the enormous pressure of the ice would be too technical for general understanding. They are fitted with water tight compartments, so that if the ship is stove in in one part she is in no danger of sinking. It is to be hoped that in case of necessity they will prove more useful than those of the Vanguard did; but it must be remembered that the Vanguard was a heavily armoured iron ship, and the Alert and Discovery are wooden ships.

The screws are fitted in a way to admit of their being readily detached and raised out of the way of damage from the ice, while the screw shafts can be drawn in.

Both vessels carry an unusual number of boats, all being constructed in a peculiar manner to meet the contingencies to which they will be exposed. They are also furnished with collapsable boats.

Next in importance to the ships and the boats, as a means of effecting the objects of the expedition, are the sledges, and here, fortunately, the expedition has the advantage of the experience of Sir Leopold M'Clintock, who may be considered to have brought sledge travelling to perfection in the numerous Arctic expeditions to which he has been attached.

The sledges are made of American elm, a tough light wood, the principle of construction being: (1) Two steel-shod runners, curving upwards at the ends, these ends being united by longitudinal bars, supported by columns resting on the runners; and, (2) Cross-bars on the top, keeping the runners apart and parallel.

These cross-bars, with a piece of canvas stretched over them as a kind of sacking, is the platform on which the tent, provisions, and all the *impedimenta* of travelling, are carried.

No screws or nails are used in the construction, excepting those securing the steel runners to the wood—all the other parts being united with hide, strips of which, soaked in hot water, are used for lashing the various parts together. In drying, the hide contracts and forms a stronger security than nails or screws could. Nails and screws would break by the extreme cold.

Of these sledges no fewer than between thirty and forty are supplied to the ships, varying in size from that adapted for twelve men to those suited to five; and also dog-sledges.

In dragging the sledges, the men wear a canvas belt over one shoulder and under the other arm, according to which side they are on. At the end of the belt is a button which, by a single turn of the lanyard round the tow-rope, at the turk's-head worked on it, remains quite secure as long as there is a strain on it, but the moment it is slackened it disengages. This keeps the men up to the mark in pulling their quota, and prevents accidents in case of the sledge breaking through the ice.

The starting load of an eight-man sledge is calculated at 1646lb., or about three quarters of a ton; this gives an average of about 2 cwt. to each man, which weight is considered the maximum for trained men.

Next in importance to the sledges are the tents. These are of three different sizes, to accommodate twelve, eight, or five, men. They are made of unbleached duck. The eight-man tent is nine and a half feet long, seven feet wide, and the same high; weight 30lb.; the others proportionately larger or smaller. The ends of the tents are spread by two poles crossed at the top, each pole end fitting into a canvas cap fitted to the tent for the purpose. The tent is secured in an upright position by a ridge-rope and stays, the latter at one end secured to the sledge placed transversely to the tent, and the other to some of the heavy gear, or to a lump of ice; two spans, set up to pegs, keep the sides distended, and two half hoops at the top help to make the tent more roomy by spreading the upper angle. A foot-cloth about a foot wide is attached to the lower edge of the tent, on which the snow is shovelled to keep the tent steady, and also to keep the wind out. Three or four small tubes of canvas serve the purpose of ventilators.

There is a flap or window at the inner end of the tent, that can

be opened or shut at pleasure from within. The tent furniture consists of a macintosh sheet, which is spread over the ground. This is covered with a duck floor-cloth, on which the duffle blanket is placed, which serves as a bed for the whole party. Then each man has his duffle sleeping-bag, with his knapsack for a pillow; a large double duffle counterpane covers the whole family. The sleeping bag is so arranged that a man can either sit up in it and take his meals, or almost hermetically close himself within it. In very cold weather a blanket foot-bag is added to his other luxuries; but when the cold becomes very extreme, especially when accompanied with wind, a tent becomes untenable, and resource is had to building a snow hut, after the manner of the Esquimaux.

The cooking apparatus is circular, made of tin, with wooden covers, the heating material being spirits or stearine used with a cotton wick. By an arrangement of the saucepans two or three articles can be cooked at the same time, the whole being protected from the weather by an outside coat made of fearnought.

Everything is arranged for sledge travelling in a most methodical manner, and although each man's appetite cannot well be measured, that which is intended to stay—if not to satisfy it—is, and that to a great nicety. Each man's wardrobe is also arranged for him, beyond which he dare not take the weight of an ounce. All is stowed on the sledge in such a way that each article can be readily found at a moment's notice. The tent-poles, pickaxe, shovel, &c. are kept outside, as is also the cooking stove on the netting at the extremity of the sledge.

Whilst on the subject of the travelling equipages, it may not be out of place to speak of the travelling itself, and this differs much with the season both in point of speed, and comfort in travelling, for as in spring time the road is good, the extremely low temperature at that period of the year makes it uncomfortable, and each man has to keep a sharp look out for his neighbour's nose, as one is quite unconscious himself of the terrible frost-bite, although it is easily detected by another; and at times you are literally dependent on your fellow-worker for the safety of your organ of smelling. The dress at this time is of the warmest of woollen garments, not furs, beyond the seal-skin cap, and the whole covered with a suit of duck, as being most impervious to the blinding, penetrating snow dust, which, if it gets into the cloth, it soon becomes like boards.

The travelling in summer, say July, when from the heat of the midsummer sun the thaw has set in, is perhaps, more uncomfortable

than spring travelling; for although the men have doffed the very heavy clothing and taken to the more civilised suit of the temperate zone, they have to wade through sludge and just melted ice without certainty of footing, and often stumbling and slipping, and with no prospect of drying their clothes when the day's work is done; so that of the two, the more severe cold of April travelling is preferable.

We will take an ordinary day's travelling without the extremes for an example, the "hurrahs" and "God speeds" of parting from our shipmates being the memory of a week, with the men well settled into their harness and daily work. After an early breakfast of chocolate and a little meat and biscuit, everything is packed for the day's journey; the men take their places at the drag-rope and away they go, considerably refreshed in one way from their night's rest, but so cold, that their fingers—notwithstanding the warm mitts—may be said to be "all thumbs." But the exercise of an hour's hard work restores circulation, and I suppose the next three or four hours may be considered the most comfortable period of the twenty-four, as the cravings of hunger have not set in, and the feeling of fatigue has not come over them, so they trudge along cheerily, and even merrily. The officer generally forms the advance guard, not only to give the line of direction, but also to select the smoothest road for the sledge—a strict attention to these duties greatly assisting the labour of the men. Occasionally he drops alongside his men for companionship, with a kind word to one and a joke to another, and stimulating exertion in all, to attain some object or some goal he has fixed on to reach that evening, or even giving a willing relief at the drag-rope to some poor fellow who is more than ordinarily done up; and so the day goes on. The period and length of the midday halt depend generally on circumstances and the necessities of the men themselves; they then lay into the rope again, and the last half of the day becomes more laborious than the first. Then comes th happy time—the halt for the night. A spot is selected for the stoppage—not on the earth, even if possible, for that is frozen, and gives off no warmth; the ice or snow is preferable. Then u - packing commences, every man having his special duty to attend to. The cook for the day, and his mate, care not for the tent; the other men attend to that. The tent is pitched in a few minutes, the position regulated by the direction of the wind, and the door being always on the lee side. The sledge is placed in position, the tent-man brushes out the floor of the tent, then spreads the

macintosh, unbends and kneads out the duffle bedcloth as well as he can, but no amount of kneading will make it flat; the stiff ridges and corners must await an hour of the heating from the bodies of the occupants before it will assume anything like the flat surface intended. The sleeping bags are arranged for the night, that for the officer at the head, or inner end of the tent, and that for the cook at the foot, or near the door, so as to be ready for preparing the early morning meal. The officer probably takes observations, and then all—with one exception—take to the sleeping bags, and all are cold and sleepy; the pipe, which is a real luxury in that cold climate, keeping a few awake. The individual excepted is decidedly the most important man of the evening—the cook. Directly the sledge stops he arranges and trims his lamp to thaw the snow, whilst another man takes the frozen pemmican and chops it up with the pemmican axe into small pieces, the splinters flying off as if he were chopping a lump of rock. By the time he has chopped up the allowance for the meal, the snow in the kettle has thawed, and the meat is put in, the cook carefully tending it until it is boiling. Then, at the sound of the dinner bell—which consists of a string of pannikins being rattled together—all rise up and a pint of good stout strong hodge-podge, smoking hot, is handed into each blanket, which opens and falls back like the head of a barouche, whilst the occupant takes his dinner; and, as the warmth of the hot condiment acts on the system, so do the spirits of the party revive, and the cheerful yarn or even the song goes round. But the poor cook has yet to make tea, the pannikins being scraped out as well as possible to hold the amber fluid. At last, tea over, the cook arranges his cooking utensils for the early breakfast, and then creeps shivering into his bag; the pipes are lighted, and what with the smoke and the animal heat of eight bodies, the blankets begin to thaw, the duffle bed-cloth to lie flat, and soon all are asleep.

Thus we have given an idea of a favourable day's march; but when we came to snowstorms and the blinding driving snowdrift—when we came to be brought up several times in the day, and as often the sledge has to be unloaded and reloaded—or the sledge falling through the ice and everything getting soaked—or any of the thousand-and-one accidents of sledge travelling—who can paint the utter misery of a day's travelling? When the men, or some of them, are ready to lie down and give up dear life itself, if only allowed; and it requires all the reasoning, nay, firm authority, of the officer, to keep his men together.

Great assistance can be rendered by the use of dogs, and the advantages of a good pack are very great, especially when short-handed, as two dogs are considered equal to one man in sledge-hauling; and instead of consuming one man's food they require but a small allowance, and more, require no clothes to wear or carry. M'Clintock sent six or seven dogs with six men, and this party worked harmoniously together over a thousand miles and through the lengthened period of nearly eighty days.

Dog-driving is no easy matter, and many here who may drive tandem or handle the reins of a four-in-hand with consummate ability would find themselves all adrift in the attempt to drive a team of dogs. The harness consists of a few strips of canvas and a single trace about twelve feet long. The dogs are harnessed three abreast, with a leader. The first difficulty is to catch your dogs and harness them—a not very easy job, as every dog strives to do exactly what you do not wish him to do; but at last they are all harnessed and a start is made, and away they go, the driver guiding them entirely by the whip, which it is necessary for him to handle effectually with either hand, and it has to be kept continually at work. As the dogs at the sides are most exposed to the whip, they naturally try to become the middle dogs by jumping over the backs of their neighbours; so that after a short time the traces get so plaited together that the dogs cannot work, and a halt becomes a necessity, and at the risk of frozen fingers the driver has to divest himself of his mitts to disentangle the traces and get the team into order again.

It is not an unusual thing that when a dog feels the lash, he immediately bites his neighbour, who bites the next dog, and so on, until there is a general fight and howling. The lash is then no longer of any use, and the driver is compelled to restore order with the handle of his whip.

The moment the whip ceases, and halt for the night takes place, the dogs fall asleep and remain motionless; but at the first sound of the pemmican axe in chopping up food, they start up like so many famished wolves, and surround the chopper, darting upon any splinters of meat which fly off. The dogs are not fed until an hour after halting; then their food—usually frozen bear or seal's flesh—is strewed over the snow and trampled into it, so that when the rush takes place the weak dogs are enabled to get their fair share of the food with the strong. Everything that is eatable or gnawable is carefully kept out of the reach of the dogs; and woe be to the unlucky wight who leaves a pair of boots within their reach.

Some doubts were entertained whether dogs would be procurable for the present expedition, owing to a disease that has been prevalent amongst them, by which many have been carried off; and an Esquimaux is loth to part with his team, as by his team he is estimated, and an Esquimaux without dogs becomes a mere hanger-on to one who has; but I am glad to say that Captain Nares was enabled to obtain twenty dogs at Disco, twenty more at Ritenbenk, and the remainder of the sixty he required he expected to obtain at Uppernavik or Proven. Moreover, he has obtained the services of two Esquimaux as dog-masters.

It is impossible to tell how far the expedition will go, or what will befall our explorers; but we now know by the return of the Pandora that the ships had safely crossed the much dreaded Melville Bay—that *bête noire* of the whalers, for it was said of old, and with some truth, that if caught between the fast ice and the moving pack, the ice would either pass under you, over you, or through you.

But steam is a great assistance in taking a ship through, and it has helped Captain Nares on to the entrance of Smith Sound, where, at Carey Islands, Captain Nares landed and left his first despatches, by burying them enclosed in a tin case, and then erecting a cairn at a certain distance and bearing from the buried despatches, according to an understood arrangement. These despatches were found and brought home by Captain Allen Young. Any vessel sent after the expedition will at once know where to search for despatch cases, which will be buried on different headlands as the expedition proceeds. Every endeavour will be made to get the ships over on the west side of the Sound, and then they will work to get to the northward.

I cannot be so bold as some in at once taking the expedition as far as the Polaris went, for, from the evidence of Kane and Hayes, the year the Polaris got so far north must have been exceptional; but I think I may in imagination take them midway between the position the Polaris obtained, and that at which Hayes and Kane were stopped, say latitude 81° or 81½°. But it is not intended that both the ships shall go to the extreme point possible. It is arranged that one shall be left in a position where there will be little danger of not being extricated, whilst the other will be the advance ship, and go as far as possible. The advantage of this arrangement is evident; for if the advance ship is beset beyond the power of being freed, the officers and crew will have the other ship to fall back on. We will place the rear ship in latitude 80°

I would wish to be guarded in what I state in regard to the progress of the ships up Smith Sound, as there are good hydrographical reasons for believing that the ice is more open, and the strait consequently more free than is generally supposed. For instance, a piece of wood about a foot long was picked up in latitude 82°, and an Esquimaux stated that plenty of wood came from the northward, and is washed up along the shore of Grinnel Land, borne by the current from the coast of Siberia. Then again, a distinct tidal wave is said to meet at Cape Fraser, on the west coast of Grinnel Land; that is, to the southward of Cape Fraser the flood tide makes to the northward; and to the northward of the Cape it flows south; and at spring tides, or the full and change of the moon, there is a rise and fall of 5½ feet.

These are most important considerations; still, the ice and the narrow straits are the great difficulties; and I believe I shall be found right in limiting, as I have, the position attained.

In speaking of the different routes, I have stated that the one this expedition is pursuing is considered to be essentially a sledge route; and it is the opinion of those connected with it, that sledging is before them to a great extent, as indeed the number and variety of the sledges taken with them, indicate. Now the first thing to be done when the ships are in the positions I have assigned to them (or wherever they may be) will be to open a communication with each other. The advance ship will know the position of the rear ship, and the rear ship will know somewhat of the direction taken by her consort; and it is not too much to say that that communication will be effected before the winter sets in.

We have now the advance ship 90 or 100 miles from the rear ship, and eight and a half or nine degrees—or say 500 miles—from the Pole. Depôts of provisions will probably be established between the vessels, the surrounding country explored in short autumn trips with the dogs, and then they will make themselves comfortable for the winter and speculate on reaching the Pole next summer.

With the appearance of the sun the work will commence. Some of the officers and men of the Discovery, the rear ship, will be transferred to the Alert, the advance ship, to aid in the great object of the expedition. The sledging parties will be organised, and an advance made towards the Pole.

It is very difficult to speculate on the progress they will make. M'Clintock, on his excursions, averaged a distance of thirteen or fourteen miles a day, whilst Hayes, in Kennedy Channel, averaged

only two or three miles; in the one case the ice was tolerably smooth round the shores of the islands which M'Clintock traversed, whilst the ice in Kennedy Channel was hummocky. Then, again, the distance from the Pole, 500 miles, is as the crow flies, or in a straight line, and as we know that the coast does not continue long to follow a straight line, and to go "across country" is not possible, we must therefore, in estimating the distance from the Pole, take that into account, either by adding to the distance or deducting it from the daily average distance of travelling, and I do not think I shall be wrong in estimating the daily average at seven or eight miles at the utmost, or by nearly doubling the actual distance. Taking then, the average daily advance at eight miles, it would take 63 days to reach the Pole from the advance ship, and that time doubled for the return would make 126 days' travelling. Now as no one sledge could do this, it must be effected on the telescopic principle, and also on Darwin's principle of selection of species. Depôts or stations will be formed on the route, to which sledgės from the ship will convey provisions and return for more, or meet and replenish returning sledges, whilst the selection will go on with regard to the men and the dogs in order to secure the "survival of the fittest" for the last draw, or the small end of the telescope, or that party which will push forward from the most advanced depôt to reach the Pole, whilst the second slide will prepare to go to the aid of the first on its return, and so on back to the ship.

It is a very easy matter on paper to cut and dry all that can or should be done, but it is a very different matter to those concerned. You cannot send a ship to the North Pole by Act of Parliament; and a very trifling matter may set aside the most elaborate calculations. Like Cæsar's "*Veni, vidi, vici*," the instructions might be resolved into almost as few words—To the North Pole—by Smith Sound—go ahead!

Never has an expedition created such universal interest, and never have the papers been more full of articles, comments, descriptions, and illustrations, than they have been in regard to this Arctic expedition. Never have officers and men been so *fêted* and made much of; never has the general public been inspired with such enthusiasm for a Polar expedition. Never have the articles of a lady's *trousseau* been inspected with more interest than the articles of clothing which the officers and men are now wearing. Their tents and bedding were minutely examined by the fairest of the fair—enough to turn the brains of the unsophisticated fellows who were to sleep in them. The cooking utensils,

pannikins, and spoons, were objects of interest; the duffle cloth was handled and felt; and I am only surprised that duffle worked into *paniers* and *tabliers* are not the prevailing fashion this winter, and the true Arctic cut, something to be particular in.

But it is no light task that Captain Nares and his companions have before them; and although I most strongly deprecate creating a visionary belief that the Pole will be attained, as most unfair to our gallant countrymen, I may confidently assert that every effort will be made that human beings can make. Many circumstances combine to increase the difficulties our countrymen will have to contend with. Let us remember that Captain Nares himself is the only officer in the two ships experienced in ice work, and it requires some apprenticeship to get your hand in that kind of work. Let us remember also, that the ships, small as they looked amongst the ironclad monsters in the docks at Portsmouth, are nevertheless twice the size of any of the ships that have preceded them in Arctic exploration; and a ship of seven or eight hundred tons is no joke to box about amongst the ice, or get off the ground if she tails on, and that with no more hands than were accorded to the smaller ships.

Then again, on what grounds is it reasoned that the distance between the supposed position attained by the advance ship and the Pole is adapted for sledging? I see more reason to argue to the contrary, from the existence of those islands, separated by wide channels that lie west of the great continent of Greenland, and which may continue to the Pole; so that to take our voyagers to the Pole and bring them home the year after next, is to lead the public to expect too much, and as a matter of course they would be proportionately disappointed if it be not accomplished. It is at the best a matter of chance, which, if unfavourable, the boldest and bravest may fail to achieve success; but if circumstances are favourable we may be sure that advantage will be taken of them to the utmost. The explorers will do their duty equally in both cases.

From the perusal of the journals and narratives of previous arctic voyagers, from the lips of many of them I have been associated with, and from a little personal experience, *I* know full well what Captain Nares and his companions will have to go through and suffer and endure under any circumstances. *They* know how much every man, woman, and child in England who understands anything about it wishes them "God speed," and the last telegram they received before leaving Portsmouth was

from Her Majesty to that effect. *We* know that the men who have gone to attempt to reach the Pole are British sailors; and although one myself, and it may seem presumption, assumption, or conceit on my part to say it; but *if* it is to be done, cheered on as they will be by the thought of "What will they say in England?" *they will do it*, for the honour of Old England—and, to the glory of God. [The following remarks were introduced incidentally by the lecturer, and are thus arranged at the end to avoid breaking the continuity of the subject.]

Auroras.—These electrical appearances are not visible in very high latitudes, but they are very beautiful when seen off the coast of Greenland; and I know no sight more impressive than on a still and fine calm night, no land being in sight, to see a vivid aurora flashing and darting through the heavens from behind a dark cloud and throwing its peculiar light over the ocean, whilst through its beams are seen the bright stars in the zenith, and from one of those dreaded ice islands, with its perpendicular sides, is reflected the soft light, and the berg itself is reflected as softly in the dark water around it. The insignificance of the speck of a ship in such a vast wilderness of waters as she rolls lazily with the swell, and the still greater insignificance of the atom, self, standing on the ship, all tend to make it a solemn and meditative scene; and cold, indeed, must be the nature that at such a time would not be moved by this silent manifestation of the wonderful works of the Creator.

Icebergs.—A few words on the formation of icebergs, as being closely connected with Arctic exploration; and I may instance Greenland for its enormous iceberg-producing capabilities. There is no reason to doubt that the whole of the interior of Greenland is a mass of continually increasing ice, affected certainly to some extent by the summer sun, but which never clears the mountain tops. Now this ice is not stationary, but, like that of the Alps, is ever on the move, slowly certainly, but surely travelling towards the coast, and with such force as to compel it to an upward movement as well as downward; and thus it travels over hill and down dale.

As the Greenland coast is indented with deep fiords, that run a long distance into the country, the ice, as a matter of course, reaches the head of the fiord first, and there forms an ice-cliff, which, as it is forced out into the fiord, breaks off, and thus it becomes the birthplace of icebergs. But I would prefer taking a coast glacier, where between two ridges of hills the cliff is formed

and is gradually forced out to sea; when one or two processes takes place to form the iceberg. If the water is deep the cliff is forced into the sea, with no rest for its base, and as it is forced out the weight of the ice causes a berg to break off and float away; or if the water is shallow and pressed out, and kept below its line of flotation, the force used to attain the position due to its specific gravity causes it to break upwards instead of downwards, and it floats away a full-blown iceberg.

The Magnetic Pole.—A question has been often asked, how Nares is to find his way as he approaches the Pole? Will his compasses act so as to guide him? and what will be the magnetic action on his compasses so far north? I should not have adverted to this subject did I not find that there are many persons who do not understand the nature of the magnetic pole of the earth, in contradistinction to the real pole, or axis. I regret to say that the poets have lent their aid to the misconception. Love is described as "true as the needle to the pole;" but the poet was either ignorant of the fact that the needle rarely points directly to the pole, or he wrote in a cynical mood, well knowing the variation—or as it is sometimes termed, the declination—of both.

Now, without entering too deeply into the subject of terrestrial magnetism, I may state that every magnet has two poles, the one possessing exactly the opposite properties of the other; the one end is attracted by the north magnetic pole of the earth, and the other by the south magnetic pole of the earth; and these two magnetic poles are far distant from the true pole. If a magnetic bar were suspended exactly in the centre in this room, so that it could move freely, it would neither point in the direction horizontally or vertically of the true pole; if it did it would point down at an angle approximate to the latitude, about 52 degrees, whereas it would be over 70 degrees; and instead of the direction being that of the pole star, which is immediately in the zenith of the north pole of the earth, it would point about 23 degrees away from it. I have here two diagrams, one representing a dipping needle, the other the ordinary mariner's compass. The dipping needle is mounted to show the vertical declination of the needle towards the pole when placed in the line of the magnetic meridian, or with the line of the needle of the mariners' compass. The declination of the needle commences from the magnetic equator, or the position round the globe where the needle is perfectly horizontal. This magnetic equator does not coincide with the terrestrial equator. As we proceed northward or southward

from this magnetic equator, the north or south pole of the needle increases its dip, until the spot is arrived at where it will stand vertical. Could we go round the globe at each ten degrees of dip, as we got north, the needle in forming those circles, would take no notice of the real pole of the earth, but would converge round the magnetic pole.

Now, with regard to the compass, the most simple explanation will be to suppose two ships, or a dozen, all steering by the compass, due north, from various parts of the equator. By following that course they would not meet at the north pole of the earth, but at the exact spot where the dipping needle stands vertical. By this I think you will at once see that the nearer Captain Nares approaches the North Pole the further he will recede from the magnetic pole, and the less magnetic influence will there be in his compasses, and, strange as it may appear, he may have to steer south by his compass, in order to reach the North Pole.

THE SCIENTIFIC WORK OF THE ARCTIC EXPEDITION.

By Captain Davis; reprinted from the "Geographical Magazine."

Shortly after Mr. Disraeli's Cabinet had resolved on the despatch of an expedition to the Polar regions, the President and Council of the Royal Society were invited by the Lords of the Admiralty to offer any suggestions which might appear to them desirable in regard to carrying out the scientific conduct of the expedition. The result of this proposal has taken the shape of a bulky manual of the natural history, geology, and physics of Greenland and the neighbouring regions, together with a series of instructions, for the guidance of Captain Nares and his officers, for the further prosecution of the knowledge already acquired and detailed in the manual. The whole has been ably edited by Professor T. Rupert Jones, F.R.S., under the direction of the Arctic Committee of the Royal Society, and published by authority of the Lords Commissioners of the Admiralty. In addition to the above-named manual and instructions, we have also a selection of papers on Arctic geography and ethnology, reprinted by order of the Royal Geographical Society, forming in all a goodly quota of scientific Arctic literature, and leaving but little to be desired for the instruction and guidance of those gallant fellows now on their way northward.

The manual consists principally of reprints and excerpts from transactions, proceedings, journals, magazines, and other widely

scattered sources, now for the first time collected within the compass of one volume. These detached papers are divided into two parts, the first relating to biology and zoology and the second to physics. Notwithstanding the haste with which the whole has been compiled, it is almost a marvel that so much has been done, and done so well, in the limited time.

The first part is subdivided geographically into three districts, the first including Davis Strait, Baffin Bay, and the coasts to the northward; the second, the great mass of islands or Arctic-American Archipelago lying between Baffin Bay and Behring Strait; and the third, East Greenland, with Spitzbergen and Franz Joseph Land.

It would be a mere recapitulation of names of authors and their works to attempt to give any account of the contents of this manual. A large portion of the contributions is from the works of Drs. Robert Brown, C. Lütken, and J. D. Hooker; but there are several most valuable monographs from the pens of other writers.

The instructions for the use of the Arctic expedition are, like the manual, divided into two parts; but strangely enough, as proceeding from the same editor, the subjects are in inversed order, Part I. of the instructions relating to physics, and the second part to biology.

The instructions for physical observations deal first with the astronomical phenomena that will probably occur in the regions in which the ships may be at the time, the eclipses and occultations having been carefully computed by Mr. Hind, the superintendent of the *Nautical Almanac*. The occultations include the stars of the fifth magnitude that may be visible in or near 80° N. latitude, and 60° W. longitude.

The suggestions for observing the tides, by the Rev. Samuel Houghton, include a summary of Arctic tidal observations already made, which, scant as they are, will prove of great importance when collated with those that will be obtained by the present expedition; but the difficulties in making a successful series of tidal observations in such a climate, as may naturally be supposed, are very great, and unless they are observed serially and with great care they are of little value. Dr. Houghton suggests hourly observations of height for one month at the times of the solstice and equinox, while at intervening periods the tide should be registered every *four* hours of *mean solar* time. This amount of observation can scarcely be expected, for at the period of the winter solstice it will scarcely be practicable, and at the time of

the summer solstice the expedition will probably have too much work to be enabled to spare observers, even should other circumstances be favourable. At the time of the equinox observations may be made with advantage, if the passages are not too much hampered with ice to prevent the flow and ebb of the true tidal wave. As much depends on the observation of tidal phenomena, it is greatly to be hoped that a good series may be obtained.

The tidal instructions are followed by those for pendulum observations for determining the figure of the earth, by Professor Stokes, the Secretary of the Royal Society; and these by directions for collecting the meteoric (cosmical) dust, as detected by Professor Nordenskiöld, in regions far distant from any source of dust.

As may be imagined, the subject of terrestrial magnetism is considered one of importance, and the three consecutive maps appended to this section of the instructions, are in themselves extremely interesting, especially those relating to inclination (dip of the needle) and declination (variation of the compass). The instructions are by no means lengthy, and may be summed up in the first paragraph, which states that "the determination anywhere in the Arctic regions of the elements by which the earth's magnetic force is usually expressed (*Declination, Inclination, and Intensity*) will be valuable."

Magnetism is followed by meteorology, the instructions for which were prepared at the Meteorological Office, from which department also the meteorological instruments were furnished. *The quality of observations* is insisted on as *of much greater importance* than the quantity, and two-hourly or even four-hourly readings are recommended. Very clear and explicit directions are given for the thermometric and hygrometric observations. As in a measure connected with meteorology, a few notes on observing auroral phenomena is added by Professor Stokes, but as these cease with a very high latitude, we fear that but little will be added to our knowledge from the voyage of the Alert and Discovery.

The instructions for ascertaining the electrical state of the atmosphere are by Professor Sir William Thomson, but the observations and the instruments themselves are of so intricate and delicate a nature that, without some previous knowledge of the subject, it would be impossible to give a fair idea of the obser vations required within the space allotted to us.

The science of optics is one which of late years has become of considerable importance, through the invention of the spectroscope and the investigation of the laws relating to polarisation of light.

This has invested the observations to be made by the Arctic expedition with a greater interest than that attaching to any previous expedition. Very precise instructions are given for observing the solar spectrum, with a view to terrestrial absorption, and the spectrum of auroras. Spectroscopes are supplied specially for each purpose.

The article on polarisation of light is, as might naturally be expected, by the Treasurer of the Royal Society, Mr. Spottiswoode, and clear and explicit directions are given for the detection of polarisation in auroras and ice-blink, suitable prisms having been furnished for these observations.

The physical portion of the instructions concludes with some very practical hints towards observations in the Arctic regions, by Professor Tyndall. Those with regard to the movement of the glacial ice, both at the coast and inland, will prove particularly instructive, should the Alert or Discovery be in a position to watch its movements by means of theodolite angles. The range of sound and the aerial echoes are also dwelt on as worthy of observation.

The instructions to the naturalists engaged in the Arctic expedition will keep those gentlemen well employed if they can attend to even a small portion of the subjects to which their attention is solicited. The first section of these instructions is by Dr. Albert Günther, F.R.S., on the mammalia of Greenland, and although the number is small, the observations that may possibly be made on them will be valuable, and particularly in their distribution or gradual disappearance towards the Pole. The naturalists are earnestly exhorted to collect any new or partly new species met with north of 80° N. latitude, and directions follow for ascertaining the peculiarities of some of the well-known species which the absence of skilled naturalists in former expeditions has prevented from becoming known.

The Cetacea are next described by Professor W. H. Flower, and useful directions are given for observing the habits and peculiarities of this interesting order. Where practicable, good and accurately-coloured drawings of the animals from actual measurements are a great *desideratum*. The contents of the stomachs are to be noticed, with a view to ascertain the natural food of the animal. The description of the different species are briefly described, but still with sufficient detail to enable an unscientific observer to distinguish them.

The instructions in ornithology will not prove difficult to carry

out, "all being fish that come into the ornithological net." Excepting in the very commonest species, specimens should be preserved of all the birds met with during the expedition. Examples of both sexes in their various plumages, of the eggs, nestling, and immature form of such as breed in the country, should be preserved. This, we should think, with the number of fowling-pieces on board, will keep the hands of the collectors well in. But there is one particular instruction to the collector not given, which we think might have been added, the more especially as the duty may fall on the unscientific, although maybe ardent collector, and that is, careful measurements of the bird as soon as possible after its being shot, and before skinning, for we may see in some of our best museums birds set up with elongated necks, such as are never seen in nature.

The instructions on ichthyology are by Dr. Günther, and should more properly have followed his paper on mammals.

Mr. J. Gwyn Jeffreys, in a short paper, gives directions for making observations on and collecting mollusca, but, excepting under very favourable circumstances, we cannot expect that much will be effected in this branch of science. The towing-net of muslin or fine gauze and the dredge are very agreeable articles to handle, and the examination of their contents very interesting to separate from the *débris* in a tropical or even temperate climate, but when everything freezes the moment it is out of the water it requires great zeal and perseverance to devote oneself to this pursuit.

Dr. Allman's paper on collecting and preserving hydroids and pollyzoa is almost too scientific for any but a skilled collector, which we think a pity, for many sailors become active collectors if taught in a simple way. His instructions on the construction and method of using the towing-net, and notes on the animals that may be obtained by its employment, are more explicit, but the same remark on the uncongenial nature of the employment will hold good as made in the preceding paragraph.

The instructions in botany, by Dr. Hooker, form one of the most interesting papers in the whole series. Apart from its direct object, it is commendable as being written in such simple language that an intelligent seaman could undertake the work of a scientific collector with very little extra aid. This may more particularly be said of the section on the collection of marine *algæ*. Particular attention is directed to the ascertainment of the power of seeds to resist cold whilst retaining their vitality, and samples of various seeds are furnished for the purpose of testing them, plain and

simple instructions being given for making the experiments, which will prove an interesting subject for study in the long winter night, when different gradations of cold may be regulated, although in this case the absence of light may possibly interfere with their germinating so freely as they otherwise would. The seeds supplied for experiment are mustard, cress, radish, turnip, pea, bean, sweet pea, wheat, barley, oats, and maize.

The temperature to which Arctic plants are exposed during the winter, where covered with snow, is also a subject for investigation.

The general instructions for observations in geology, by Professor A. C. Ramsay and Mr. Evans, the President of the Geological Society, commence with an enumeration of the implements and instruments required in carrying them out. The directions are very explicit, and are greatly aided by woodcuts, particular instructions being added for glacial observations.

Professor N. Story Maskelyne, F.R.S., has added a paper on collecting mineralogical specimens, in which he lays much emphasis on the necessity of collecting specimens of every distinct kind of rock, and he adds: "To the mineralogist rock specimens have a special interest, as being aggregates of minerals, and often containing crystals in cavities, or otherwise distributed through them, from the presence of which the history and associations of the rock itself may be gathered. Hence a judiciously made collection of rocks has the character of an index to the petrology of a whole country."

The subject of meteorites and meteoric iron in connection with Greenland is naturally an interesting question, and directions are given for a careful examination at a place called Ofivak, in the island of Disco, from whence Professor Nordenskiöld brought some large masses of meteoric iron, and since which a mass of iron of nearly twenty tons in weight has been brought.

The concluding paper of the instructions is by Mr. J. W. Judd, on volcanoes, or evidences of volcanic action, a class of inquiry which will prove difficult in an Arctic continent.

The "Arctic Papers" of the Royal Geographical Society form an excellent addenda to the manual of the Royal Society. Nor can they be termed altogether reprints, as, for instance, the principal part of the paper, "Notes on the State of the Ice," by Admiral Sir R. Collinson, which, although having little connection with the route followed by the present Arctic expedition, is, nevertheless, of great interest, as bringing together a number of stray, and

otherwise detached, observations, of general importance. The notes may prove of great service to Captain Allen Young's Expedition; for if he is successful, as we hope he may be, in getting to the southward through Victoria Strait into Dease and Simpson Strait, there is every probability of his being enabled to coast westward along the north of America to Behring Strait. The first article, "On the Physical Structure of Greenland," is also one of importance and great interest. The article on the "Western Eskimo," by Dr. Simpson, is full of observations on the habits and customs of that most interesting people. The work closes with a number of questions of *desiderata* for the consideration of the voyagers.

As a kind of supplement to these manuals and instructions, the Hydrographic Office of the Admiralty has issued a pamphlet of hydrographical remarks on Davis Strait, Baffin Bay, Smith Sound, and the channels northward to 82½° N., compiled from various authorities.

"In the multitude of counsellors there is safety;" but when we glance at this pile of advice and instructions, our thoughts can but turn to the means for carrying them out. Certainly two scientific gentlemen are appointed to the expedition, and we do not doubt their zeal and ability; but, apart from those observations on magnetism, meteorology, &c., that will devolve on the officers of the ship, there is sufficient to engage the attention of half-a-dozen scientific men, not to specify more particularly a trained geologist, the want of which is a serious loss. True, some volunteers may be found among the civilian officers of the expedition. The medical staff will probably greatly aid in collecting and preserving specimens; the chaplains, also, may do good service beyond their clerical duties, if so disposed; and as the opportunities of collecting will be but few—for the ships and travelling parties cannot afford to be delayed for the purpose of collecting—it will be at those opportunities that a number of collectors will be most desirable; so that, with the guidance of the skilled gentlemen, we may still hope to realise a good harvest from the scientific work of the Arctic Expedition.

SOAP BUBBLES.

A LECTURE delivered in the Hulme Town Hall, Manchester, on Wednesday, November 3, 1875.

BY PROFESSOR RÜCKER.

IN the museum of the Louvre, in Paris, there is a vase which has by some strange chance been handed down to us through the long ages which have proved fatal to many others far more worthy of preservation than itself. It was manufactured in Italy—before the foundation of the city of Rome—by the ancient Etruscans, and it is decorated—and this is the reason I bring it to your notice this evening—with a design representing a group of children blowing bubbles. This ancient relic of those early days incontestably proves to us that the art of performing that beautiful experiment, if not with soap and water, at least with some one of the comparatively few liquids with which it can be satisfactorily undertaken, has been known at least for 2,500 years. But though generation after generation the children amused themselves with it, century after century passed away leaving unanswered, and in all probability unthought of, the numerous questions which it cannot fail to suggest to us. Why is it so easy to blow bubbles with some liquids, and so hard to form them with others? Why does a bubble when blown at the end of an open tube gradually contract and disappear? Why, when it bursts, does it not still remain a liquid film, but is shattered to an almost imperceptible dust? These and a hundred others remained unanswered, and, as I have said, perhaps un-put until after the genius of Newton had attacked, the far more difficult problem of the colours which bubbles display. To-night, however, I hope to be able to give you the answers to some of these so long delayed inquiriess, as it is now perhaps 200 years since men of science began to turn their attention to the phenomena of liquid bubbles, and to those properties of liquids on which they depend, and their efforts have been rewarded with no small measure of

success, although it is certainly only within the time of many of us here that they have been able to give anything like a complete explanation of them all. In order, however, that we may understand how best to study the laws and constitution of a soap bubble, it is necessary that we should in the first place clearly comprehend what it really is. We all know how soap bubbles are ordinarily formed. A common tobacco pipe is dipped into a mixture of soap and water, and when it is withdrawn a thin liquid film stretches across the mouth which we can blow out into a bubble, and then shake off and detatch from the tube. I will now perform the experiment of blowing a bubble before you; only instead of employing a tobacco pipe, I will use this glass funnel, and for the common soap and water, I will substitute a mixture of Castile soap, water, and glycerine. [A large bubble was speedily blown, and it showed the usual beautiful colours. This and the succeeding experiments were dexterously and successfully performed, and were much applauded.]

You now see how, by using a proper liquid, and by taking proper precautions, we are able to obtain bubbles of enormous size. But I wish you for a moment to confine your attention to the bubble, not in its full-blown beauty, as you saw it just now, but rather in that stage in which it was merely a thin film covering the mouth of the funnel. Now, this film was originally the topmost layer of that portion of the liquid enclosed by the funnel, which as I withdrew it skimmed off a thin slice from the surface—a slice so thin that had I allowed it to drain for a while its thickness would not have exceeded four millionths of an inch. But although the total quantity of liquid contained in it was so small, the surface of the film was no less than twice the area of the orifice of this large funnel. Hence, both from the method of formation of the film, and also from its constitution when formed, it is evident that if, in any respects, the surface of a liquid differs from the internal mass, if there are laws which govern, and forces which are at play on the surface, the effects of which we do not recognise elsewhere, that these peculiar properties must be to us of primary importance, if we would understand the theory and constitution of a soap bubble. The course which I shall adopt this evening is, in the first place, to study the laws and forces which are in operation on the surface of a liquid, and after that I shall try to show you how they may be used to explain the phenomena which we observe in the short but brilliant life of a bubble.

I have upon the wall a diagram on which three of the principal

properties of the surface of a liquid are enunciated. That to which I wish first to draw your attention is that the surface of a liquid is in a state of tension. It is necessary that before we go any further you should have a clear comprehension of the meaning of this word "tension." I have here a piece of indiarubber, and if I stretch it with my hands I throw the whole of it into a state of tension. The peculiarity of this state is that if I were to divide the indiarubber into two portions with a sharp knife, the parts, no matter where the incision was made, would instantly fly in opposite directions, and each would become shorter. But what each of those parts would then actually do—that is contract or become shorter—each is now tending to do; but since it could only become shorter by elongating the other part, and as that is pulling in an opposite direction with equal force, the two forces neutralise one another, and the whole remains in a state of rest, and also in a state of tension. If then we generalise from this particular instance, we may define a state of tension as follows: that a body is said to be in a state of tension when each of any two parts into which it may be divided tends to contract and to expand the other. You observe, then, that the tendency of one part to extend the other is the criterion of a state of tension; and I will now show you a couple of experiments which will, I think, enable me to prove that it exists in the surface of a liquid.

I have here a small iron ring, and stretched loosely across it, from side to side, there is a piece of cotton. I dip it into a vessel containing some of the soap mixture I used just now, and it comes out with a film adhering to it precisely in the same way as the funnel did. I now show you upon the screen the image of the ring with the thread stretching across it, and resting upon the thin liquid film. If what I have just been saying be true—if each portion of the film be in a state of tension—then each of the parts into which the thread divides it is tending to contract and to expand the other. Thus, the thread is acted upon by two forces: the portion of the film to the right is tending to pull it to the right, and the portion on the left is tending to pull it to the left; but inasmuch as these two tendencies are equal and opposite, the effect upon the thread is as if they did not exist; that is to say, it will remain at rest in any position on the film. I will now move the thread about on the film with a wire, showing that it will remain wherever I place it. I distort it and put it in any position I like. Let us, however, consider what will happen if I break the film upon one side of the

thread, and leave it uninjured upon the other. The surface tension, destroyed upon one side, will remain in action in the unruptured film, and therefore we should expect the thread to be pulled towards the uninjured side. We can easily put the matter to the test of experiment. I break one side by touching it with a hot wire, and what we foresaw occurs, the thread is instantly pulled towards the side which the wire did not tear. This experiment proves that the surface of a liquid is in a state of tension. I have, however, another to show you upon the same point, which will add to our knowledge upon the subject, for it will not only show that the tension exists on the surface, but that in different liquids it exists in different degrees of intensity. [Experiment.] You now see upon the screen the image of a few drops of coloured water, which are placed upon a glass plate. I dip a glass rod into some pure water and touch the coloured film with the drop which adheres to the end. As you see, nothing very particular happens. There is only a slight diminution of the blueness in the centre, owing to the fact that the coloured water has been mixed with the pure water. Now I will dip the rod into alcohol, and you will see a different result. As soon as I touch the blue water with the alcohol a motion occurs, and it moves rapidly away from the point at which the contact took place. Now let us consider shortly what the explanation of this phenomenon is. The surface of the water and the surface of the alcohol are alike in a state of tension; but the tension of the surface of the water is greater than that at the surface of the alcohol. At the moment I put the drop of alcohol upon the water we had a small drop of alcohol surrounded by a large quantity of water, and between the two there was a line of demarcation, which we may, for simplicity's sake, liken to the thread you saw just now. When I destroyed the force of the tension in the first experiment on the one side, the force which remained on the other side pulled the thread towards it. In this case, the force was acting on both sides; but the force at the surface of the water pulling away from the centre of the alcohol drop was greater than the force at the surface of the alcohol drop pulling towards its centre. The consequence was that we obtained a motion in the direction in which the greater force was acting—that is, in the direction in which the water was pulling away from the centre; and this continued—the water and alcohol moving farther and farther away, until the two became entirely mixed together. An experiment similar to the may be performed after dinner in the evening. When we pour

some wine into a glass we generally in doing so wet the sides, and the result is a thin film of liquid adheres to them above that portion of the glass which is filled with wine. This film soon contracts into drops, and each of these drops consists, as all wine does, of a mixture of water, alcohol, and certain other substances, the presence of which we may for the moment neglect. Alcohol, as you know, is an extremely volatile fluid, which evaporates very rapidly, and therefore above the surface of the liquid there is a small atmosphere of alcohol formed by evaporation from the wine. This evaporation goes on in the drops as well as in the main body of the wine, but more rapidly at the upper surface of a drop than at the lower; the reason being that the lower part is more completely immersed in the little cloud of alcohol which hangs over the wine itself. A drop is thus formed composed in the upper part of water, with comparatively little alcohol, and in the lower part of water with a larger proportion of alcohol. The experiment I have just shown proves that the tension in the upper part must be greater than that in the more alcoholic or lower portion of the drop. Hence you may often see drops of wine actually running up the side of a glass, in obedience to a force exerted in an upward direction, by the greater surface tension of the portion containing the larger percentage of water. A very important deduction may be made from the fact that the surface of a liquid is in a state of tension. You saw in the first experiment that as soon as the film on the one side of the thread was broken, that on the other side contracted very rapidly, and took up a form with as small a surface as was possible under the circumstances. If we were to generalise from this particular instance, we should be led to the conclusion that because the surface of a liquid is in a state of tension, and thus each part of it is tending to contract, that therefore it will always assume a shape which will have the smallest possible surface. I will now show an experiment to illustrate this fact. I have here a tube formed of four plane pieces of glass, through which I shall be able to send light, and so show you the image of its contents on the screen. It forms, in fact, a little box of glass, the ends of which are open, one of them being considerably narrower than the other. I now put the larger end of this tube into a mixture of soap and water, and I withdraw it with a film adhering to it. This film has a tendency to assume that shape which has the smallest possible surface; and evidently by moving up the tube towards the narrow end, its surface can be made smaller than it is at present.

You now see on the screen an image of the tube. I move it for a moment in order to form the film. You now see the image of the film, and I think you will observe that it is slowly moving up the tube, and therefore that its surface is becoming smaller and smaller. The experiment might be prolonged until the film burst; but at all events you have there sufficient proof that it moves into a position in which its surface is diminished. And further, inasmuch as the image of the tube is turned upside down on the screen, what appeared to you to be a motion from above to below, was, in fact, a motion from below to above, the film was in reality moving upwards, although to you it appeared to be moving down. It was really raising its own weight instead of being pulled down by it. We have thus now established this quality of liquids, namely, that their surfaces tend to become as small as possible, and we may extend the law to another and very interesting case.

Let me suppose for a moment that I take a mass of clay: it is evident that I could mould it into an infinite number of different forms; each of these forms might have precisely the same volume, might occupy exactly the same space, but they might all have very different surfaces. For instance, if I took a rolling-pin and rolled the clay out into a thin disc, and then compressed it into a round ball, it is evident that although the volume might be precisely the same in the two cases, the area of the surface would be much greater in the disc than in the ball. Now, in the experiment I showed you last, the film moved up the tube, because it had a tendency to diminish its surface as far as possible; but if I had continued the experiment longer—if I had allowed the film to move up to the narrowest part of the tube, it would, even then, only in part have satisfied this tendency, and not have done so completely—it would have attained the smallest surface possible under the circumstances, though not the smallest possible surface. The reason why it would not have done so is this: that forces were acting upon it other than that which tended to make it contract, for it was also affected by the force of adhesion to the sides of the glass tube; and as a matter of fact, liquids are ordinarily subjected to the action of no less than three distinct sets of forces. The first of these is the attractive influence of the earth, or the weight of the liquid; the second is the adhesion of the liquid to the sides of any solid vessel in which it may be contained; and the third class comprises those forces which are at play in the liquid itself. It is evident, then, that the form which a liquid

takes will not be due to any one of these, but to all three. The form which it would assume if left to the action of its molecular forces will be modified in the first place by its weight, and in the next by the adhesion to the sides of the solid vessel. Hence the question arises, if we take a liquid free from both these disturbing forces—free from the attractive influence of the earth, or practically so, and free also from the force of adhesion to the sides of the solid vessel—which of all the possible shapes into which I might mould my mass of clay would the liquid assume so as to have the smallest possible surface? This question we are able to answer very easily by means of experiment, and the method by which we do so depends upon the application of an extremely simple principle. When we place a stone in a mass of water we have, in order to immerse it entirely, to push aside, to remove to the right and left a certain quantity of water, the volume of which is precisely equal to the volume of the stone; and the stone sinks to the bottom, because its own weight is greater than the weight of the water which it has so displaced. A piece of cork, on the other hand, would rise to the surface, because its weight is less than the weight of the water equal in volume to itself.

If we could obtain a body the weight of which was precisely the same as the weight of the water it displaced, it would have no tendency to sink or swim but would remain at rest in any part of the water into which we might choose to place it. Hence this body, would be practically free from the attractive influence of the earth, and we should have succeeded in neutralizing the force of gravity, since a body having no tendency to rise or fall might be considered as removed to such a distance from the earth as to have no weight. Of course, this conclusion is independent of the fact whether the body introduced into the water is a liquid or a solid, and we may substitute for the water any other liquid; but if we employ two liquids, they must satisfy the following conditions. In the first place, they must not mix together, as wine and water do, but must remain separate, like water and oil. In the second place, the weight of any volume of one must be exactly equal to that of the same volume of the other, and in the third place, the two liquids must have, when in contact, no chemical effect upon each other. Could two such liquids be found, a small quantity of the one introduced into a mass of the second, would be a state eminently favourable for determining the shape which it would assume under the influence of its surface tension

alone. It would, as I have pointed out, be free from the attraction of the earth, and it would also be free from the force of adhesion to the sides of a solid vessel. It would however be extremely difficult to find two liquids which would satisfy these conditions; but although we cannot find them to our hand, we are able to manufacture them. Water is a liquid which is heavier than oil, and alcohol is on the other hand lighter than oil, and if we mingle water and alcohol, we may make a mixture, the weight of any given volume of which is precisely equal to that of the same volume of oil, and by introducing a few drops of oil into the mass of alcohol and water of the right density, we ought to succeed in observing the form which a liquid assumes under the influence of its surface tension alone. [Experiment.] You now see upon the screen the image of a mass of oil in a mixture of alcohol and water of the kind I have just described; and you see that our question is at once answered—the oil assumes a spherical form. From this we learn that a liquid if left to the action of its surface forces alone will become a sphere. But inasmuch as the effect of the attractive influence of the earth, or the weight of the liquid, increases with the quantity we use, while on the other hand the surface tension or its own moulding molecular force remains precisely the same, we should, if we use a large quantity of liquid, expect the weight to be the particular force which determined its shape; and if we employ a small mass of liquid, then the surface tension growing, proportionately greater, would become the more important. Thus it follows that, although we have to use the most accurate adjustment in order to obtain a sphere of oil an inch in diameter, every rain-drop, every dew-drop, and every soap-bubble are in themselves almost mathematically accurate spheres. It is very possible, of course, to make a liquid assume any number of other shapes you please, but I wish now to draw your attention to the fact that we are able to give it another very simple form, namely, that of a cylinder: and I will show you upon the screen the conversion of a spherical soap bubble into a cylinder. You now see the image of a glass funnel. I take another of precisely the same dimensions, and blow upon it a small bubble, which I make adhere to the first, and then I draw it out into a very accurate cylinder. This proves that the form of a quantity of liquid may, under proper conditions, be cylindrical, but if we make the cylinder of such dimensions that the length is very considerable in proportion to the breadth—then, the liquid will only retain the cylindrical form for a very short time, indeed. The slightest jar

or disturbance of any kind will of course make it deviate from its shape, and that deviation when once begun is continued, as it were, by the liquid of its own accord. The series of transformations through which the cylinder will go, I have represented for you in the diagram. At the top is the long cylinder, which represents the liquid in its first state. Assuming that it is slightly disturbed, you see that it swells out in some places and contracts in others; and the elevations and depressions grow greater and greater until the mass of the liquid becomes as in the lower figures, little more than a series of balls tied together by very fine liquid threads. The transformation does not end here; the threads are soon broken, and thus what was originally a continuous cylinder is transformed into a series of alternately large and small spheres. I shall have to make use of this particular transformation of the cylinder later in my lecture; but I wish for the moment to call attention to the fact that one very interesting instance of it is observed whenever water flows out from the bottom of a vessel through a small circular hole. In such a case the form of the column of water would be approximately that of a long cylinder. But, as I have already pointed out, this is a state of what is called unstable equilibrium—of equilibrium which may exist for an instant but not for a longer time. Hence the above series of transformations are gone through. We have alternately contraction and elevation; these go on until at length the falling column of water is broken up into a falling column of drops.

We must now, however, pass on to another property of the surfaces of liquids, namely, that they press on the liquid, or air which they contain, in much the same way as a blown out bladder presses on the air within it. I will show you an experiment illustrating this in the following way: If a bubble presses on the air within, then it is evident that if we made a hole in its side, the tendency of the compressed air would be immediately to escape through the hole, and we should have a current of air flowing out of the bubble which would thus become smaller. I will blow a bubble at one end of a glass tube, and leave the tube open at the other end; we shall thus have a small hole formed in one side of the bubble; which, if our theory is correct, will gradually contract and disappear. You now see on the screen, images of the ends of two tubes. I have the power of cutting off one tube entirely from access to the other; and, I do so now, so that you will, if you please, consider for the purposes of this experiment that tube only as existing at the extremity of which I shall blow the bubble.

You now see the image of the soap bubble which as long as the tube is closed remains unaltered in size; I open it and it now at once contracts and disappears. This, then, conclusively proves that the air in the bubble was compressed. I will now go a step farther, and show that the amount of this compression depends on the size of the bubble. If it be large, the air is not so much compressed as if it be small. Let us consider what would happen if I formed bubbles at the two ends of a tube. If they were of the same size, evidently—the one pressing the air in one direction, and the other pressing it in the other with equal force—no effect would follow. If, however, one bubble were smaller than the other, and what I have said be true, the small one would compress the air within it, and drive it from left to right (say) with greater force than the other would tend to drive it from right to left; hence the air would flow from the small bubble to the large one, the large bubble would increase, and the small one diminish The smaller the bubble, the more the air would be compressed; and thus the current would become greater and greater, until at last we should see the small bubble entirely disappear, the large one having absorbed all the air which it previously contained. I will try to show you this on the screen, first disconnecting the two tubes I blow at their ends bubbles of unequal size. I will now place them in communication, so that the air can pass from the one to the other. You see, the small bubble contracts and the large one expands, and we thus learn that the pressure of the smaller or more curved bubble upon the air is greater than that of the less curved one.

I now come to the third property of liquids of which I wish to speak; and that is that the surface of a liquid is generally either more or less viscous than the interior. With reference to the word viscous, you will find a familiar example of two liquids which differ very much in this property of viscosity in treacle and water. Take a vessel of treacle and a vessel of water, pour the liquids out, and note the different way in which they behave; the water flows out smoothly, one part slipping over another, whereas the treacle comes out in a great rolling mass, which seems to stick to the sides of the vessel. Again, put a spoon into a vessel of water, and move it through the liquid, you will find little resistance to its motion, the water seems to flow away to make room for it and closes in again immediately behind. Try the same experiment with the treacle and you will find the resistance very much increased; in front of the spoon

a little heap of liquid gathers, which subsides but slowly, and there is a depression behind which is as slowly filled up. It is evident that there is some difference between the interior constitutions of the treacle and the water; and that difference consists in this, that the particles of which the treacle is composed move among themselves with very much less facility than do those of the water. The fact then of one part of a liquid moving more or less easily among the other parts is that which distinguishes one from another in respect to their viscosity. In a very viscous body, like treacle, the parts move with difficulty; and in a non-viscous liquid like water, they move with comparative ease. The fact which I wish to impress upon you this evening, is not that one kind of liquid differs from another; but that one part of a liquid may differ from another in respect of viscosity; and that as a general rule the surface is more or less viscous than the interior. I will now show you an experiment which will illustrate this fact in a very striking way. I have in a glass vessel a little magnet, which, when I bring near to it a larger magnet, will easily and readily follow its motions. The vessel also contains a mixture of water and a substance called saponine. This saponine is extracted from the horse chesnut, and is, as far as I know, chiefly interesting on account of the extraordinary effect it produces on water when mixed with it. In making the mixture, I have added only one part of saponine, to sixty of water, and, to look at, it retains the properties of water; it is colourless; it has none of the viscosity of treacle. In fact the saponine has next to no effect on the interior parts of the water, but it has a most extraordinary and marked effect on the surface; and that I will now try to illustrate. You now see upon the screen the image of the magnet, and the vessel at the bottom of which there is the mixture of saponine and water. The magnet is at present about an eighth of an inch above the liquid. I bring near the large magnet, and you see how easily it follows its motions. I will now pour in some of my mixture until the magnet lies upon the surface, and I then again bring the large magnet near it. It is now upon the surface of the mixture, and you can see some of the bubbles formed as I poured the liquid in. I bring the large magnet as near as it was at first, and am moving it, but it produces no effect. I bring it nearer and nearer—still no effect. I bring it so near that you can see its shadow, and still the magnet remains absolutely motionless. On the surface of the liquid then we have found that the little magnet is totally insensible to the attractive force

of this large one. You may say that the same would happen in the case of glycerine or treacle. It might; but now comes the extraordinary part of the experiment. I pour in some more saponine and water, until the little magnet lies a quarter of an inch below its surface; I then bring the large magnet near, and you see the result.

It moves almost as freely as in the air itself. Hence we have a most convincing proof that the surface viscosity of this solution is very much greater than the viscosity of the interior of liquid; and that the resistance offered to motion by the surface is many times larger than that experienced by moving bodies in the interior.

Another experiment will illustrate this enormous surface viscosity of the mixture of saponine and water in a still more striking way. I have already explained to you that if we blow a bubble at the end of an open tube, the bubble will gradually contract until all the air is expelled. What however will occur if, instead of simply allowing the bubble to drive the air out, I suck the end of the tube and draw it out more quickly? I will first perform the experiment on some of the soap and water I have used before, and you will see that although the bubble will contract more rapidly than before, it will retain throughout the whole of the experiment its spherical form. I will now repeat the same experiment with saponine and water. In this case, on account of the great viscosity of this thin film it will be unable to follow the retreating air as quickly as it must do to retain its spherical form; the consequence is, it will be unable to retain that form, and it will therefore collapse and wrinkle up into a purse-shaped bag. [Experiment.]

I hope I have succeeded in proving to you that these three properties of liquid surfaces exist. I must now go on to explain how they can be applied to the theory of soap bubbles. Let us suppose, in the first place, that a bubble is rising in a vessel of water. It will tend to assume a spherical form; but as it rises to the surface it will be flattened in the direction in which it is moving, and, instead of being a perfect sphere, it will be longer in one direction than the other. Evidently, as it moves, it has to displace the water in front of it, which flows away to the right and left out of the way of the bubble. But, as I have explained, all liquids offer a certain amount of resistance to the motion of one part upon another; and although the resistance offered by water is extremely small, it must be taken into consideration. The liquid, therefore, has to flow out of the way of the advancing bubble, and to overcome the resistance offered

to its motion; but as the bubble rises nearer to the surface it moves faster and faster; and therefore the water must be removed from its path more and more quickly. But the resistance offered to its motion becomes greater the faster it moves; hence you have the bubble rising more quickly, the water being obliged to get more quickly out of the way, and finding more and more difficulty in doing so, and having, when the bubble gets very near the surface, less space between the bubble and the surface to flow away in. The result is that the water cannot get out of the way, and therefore the bubble carries it up with it and forms a thin liquid film, which we see as foam upon the surface, through which the bubbles of air are rising. Supposing the bubble thus formed were placed upon a solid plate, it would have the form of half a sphere; and as the bubble compresses the air in it, the air would press upon the plate; but the plate would be able to resist the pressure, and the bubble would remain a hemisphere with a flat base. If, on the other hand, the bubble were formed on the surface of a liquid there would be precisely the same pressure on the bottom, only it would be acting on a medium which would give way to it; the liquid therefore would yield to the pressure of the air, and we should have the bubble as it were a little buried in the liquid by its own pressure. As the pressure increases with the smallness of the bubble, we should expect a small bubble to be very deeply buried, and a large bubble to be slightly buried. [Experiment.] I will now pour into the cell, the image of which you see, a small quantity of liquid, and blow in it a very small bubble. You now see the images of two bubbles which have risen to the surface, and that they are very much buried in the liquid by virtue of their pressure. I will now blow a large bubble. You see that within it the surface of the liquid is very much less depressed. I will blow a still larger one. Now I have succeeded in blowing a very large bubble, and the lower part of it is not appreciably depressed. I will now blow a great number of bubbles in contact, and will then point out one or two facts. You now see that odd network which represents a great number of bubbles. There are two points I wish you to notice. In the first place, when two bubbles meet, the surface between them may be either plane or curved. It is plane if both bubbles are of equal size, and therefore compress the air within them with equal force; but if they are unequal, the smaller bubble, compressing the air more strongly, indents the larger, and the surface which divides them is curved. Notice also

another very curious point, namely, that in no case do more than three bubbles meet in a point, excepting for an instant. This follows from the law that a large number of bubbles, as well as each one, will assume the smallest possible surface. I cannot go into the proof of this, but it follows from the law I have already given you. As the bubbles form, collapse, and disappear, you see that they always so arrange themselves that no more than three shall ever meet in a point.

Now, then, we have got our bubble on the surface of the liquid. Let us consider what will happen to it after that. Evidently the liquid of which it is composed will run down the sides by virtue of its own weight; but there will be a certain resistance to this motion, greater or less as the viscosity of the surface is great or small. Hence, there are two different dangers which may beset the bubble. The first of these is that when the surface viscosity is small, then the liquid runs down the sides of the bubble very easily; the consequence is the bubble becomes very thin and bursts. There is, however, an opposite danger which may imperil the bubble when the surface viscosity is great; and that is that the liquid does not flow down in a straight line or regular curve, but in irregular masses, which every now and then tear away from each other. Now these ruptures make little holes in the surface of the liquid; and when a hole is made the surface tension tends to tear the liquid away, and to make it bigger. If the liquid has a very considerable surface tension, the small holes in the surface may be so instantly turned into large ones that the bubble may burst. This is, however, less likely to occur when the surface viscosity is small than when it is great, because in that case the liquid flowing in from all sides can more easily fill up the hole, and restore the damage done, before it becomes dangerously large. The best kind of bubble for lasting is one in which the surface viscosity is tolerably large, so that the sides of the bubble may not become thin too quickly, and in which the surface tension is not too great, so that any small fractures which occur may not be instantly enlarged. When we find a liquid which has these two properties, we have all the requisites for making good bubbles; but sooner or later a hole is made, and then the bubble bursts, and in a way which is probably very different from what, *à priori*, we should expect. In the first place the orifice which has been formed becomes rapidly larger, the surface tension which acts all round its edges and pulls the film away from its centre tending to enlarge it. Secondly, the surface of

the liquid is necessarily very much curved all round the hole, and a greater pressure is therefore excited at that part by the surface on the liquid which forms the interior of the film than elsewhere. Hence the liquid becomes heaped up around the hole into a ring which is thicker than the rest of the bubble, though its thickness is very small compared with the diameter of the hole. The liquid in the ring is thus in circumstances somewhat similar to that in the long cylinder we have already studied—it undergoes a similar series of transformations and is broken up into drops which are flung away from the bubble. Another ring is instantly formed and as instantly broken, and the process is repeated again and again with inconceivable rapidity, until in a very small fraction of a second a little cloud, composed of the numerous minute drops which have been formed, is all that remains of the bubble.

I must now draw to a close. I have discussed with you, as well as I could in the short space of time allotted to me, the history of a bubble from its birth, in the bosom of the liquid, to its dissolution in the air above. The facts and experiments I have brought to your notice have been, I hope, in themselves sufficient to attract you; but I think they will acquire an additional interest if, before we part, I tell you something about the man to whom we owe most of our knowledge on the subject of my lecture. I mean M. Plateau, the Professor of Physics in the Belgian University of Ghent. This gentleman began his studies on liquids when a young man, and was already well known for his success in scientific investigation, when a misfortune overtook him which one would have thought would have put an end to his further researches. He became hopelessly blind. A misfortune like this would have crushed a weaker man; but in the case of Mons. Plateau it served to show the genuine metal he was made of. He spent the long hours of darkness not in useless repining, or vain regrets, but in endeavouring to advance the knowledge of his race by pondering over the unsolved problems connected with the subjects he understood so well, and in devising experiments, often of the most exquisite ingenuity, for putting his theories and conclusions to the test. These, which he could no longer perform for himself, were undertaken for him by a devoted band of friends, amongst whom was his own son; and the result has been not merely a very large addition to our knowledge of the properties of the surfaces of liquids, but what is perhaps far more important, the presentation to the world of a spectacle of

victory over almost overwhelming obstacles such as it has seldom seen. It is not well that our knowledge of scientific facts should be entirely divorced from an acquaintance with the lives and labours of their discoverers, or that we should come to regard them simply as a sort of revelation made to a fortunate few, to the rich inheritance of which we have been lucky enough to succeed. The men who built up the pile of modern science were not of those who sit still and wait with folded hands for some inspiration, they know not whence, rather they performed their tasks, and won success amid difficulties and discouragements to which we in happier times are strangers. But while rightly ready to pay our homage to the great achievements of the past, we should ever be watchful to honour duly deeds which will cast a lustre upon our own time; and among these the life-work of Mons. Plateau holds in some respects a position second to none. Others may deserve a higher place for the number, or practical or scientific importance, of their discoveries, but none have more honestly earned the praise due to those who have done what they could; and the world, which is so apt to appropriate the work and forget the worker, should be taught at all events to remember this, that we owe some of the most charming experiments in the whole range of physics to one who himself has never beheld many of them, and of whom with respect to the rest, we must in all sadness say, he "shall see them again no more for ever."

THE

BIRDS OF THE GLOBE.

A LECTURE Delivered in the Hulme Town Hall, Manchester, on Wednesday, November 10, 1875.

BY R. BOWDLER SHARPE, Esq., F.L.S.,

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LADIES AND GENTLEMEN,—I cannot trouble you with a very long introduction this evening, because I have a very extensive subject to speak to you about—no less a one than the whole of the Birds of the Globe; and I cannot attempt or hope to give you more than a *very slight sketch* of such a large subject. The way in which I propose to introduce to you the birds of the globe will be by means of coloured illustrations of the principal families. On these I hope to make a few explanatory remarks as the lecture proceeds. You must understand that having devoted nearly the whole of my life to the study of birds, there is no one knows better than myself how impossible it is to illustrate the subject in its entirety *in the short space of one evening's discourse.* No person could hope in a single lecture to give more than a mere sketch of the birds which are found on the earth's surface; and therefore I request you to regard the present lecture as preliminary.

I am not going to weary you with many details of classification, for the very simple reason that at present naturalists are not agreed among themselves as to what is the most natural classification of the class of birds. One zoologist tries to classify them according to their muscles; another according to their bones; some adopt merely external features; and as these are the easiest to understand I am going to use external characters to give you some idea of the different orders of birds this evening. At the same time I must acknowledge the assistance I have had from the recent papers of

Professor Garrod, who, by his study of different anatomical and osteological characters of birds, bids fair, before long, to present us with the most natural classification which has yet been proposed; at the same time he would be the first to admit that his systematic arrangement is not as yet perfected. I believe, however, that the natural system will be best explained by the man who correlates the internal structure of birds with the external form; for the latter has surely been the result of internal modifications or of habit. A classification founded principally on personal observations of birds in a state of nature, and therefore eminently a *natural* one, has been propounded by our great countryman Wallace, to whose researches I am continually indebted, and in the arrangement of the series of birds in this evening's lecture, I have been to a certain extent influenced by the writings of this distinguished traveller and naturalist.

There are certain great natural orders which there is no difficulty in recognising; it is on the classification of the minor divisions, such as the families and sub-families, that more discussion has arisen. It seems to me immaterial in what order we take these natural groups, which are of equal value, and I shall, therefore, commence with the Birds of Prey, or *Accipitres*.

The birds of prey are remarkable for their sharply-curved bills, and also for their strong and powerful talons, characters which are well represented in the bird's leg which we have before us now. We will roughly divide the birds of prey into three sections: Vultures, Hawks, and Owls. The first illustration is that of an Egyptian Vulture. [The lecture was profusely illustrated with coloured drawings of birds, which were shown by the oxy-hydrogen light.] Now the vultures, though not very handsome, and certainly birds of very filthy habits, are highly interesting as a study. For many years naturalists have been divided in their opinion as to whether the vultures sought their prey by means of a highly-developed power of smell, or a highly-developed power of sight. The celebrated naturalist, Waterton, who was looked upon as one of the keenest observers of his age, always said that the vultures hunted more by smell than by sight; and he adduced many experiments made during his travels in South America to endorse this idea. But the balance of evidence collected by careful naturalists up to the present time is decidedly opposed to that view; and there can be little doubt that the vulture hunts by sight. Thus if an animal is wounded and falls dead it is not the

effluvium arising from the carcase which attracts the vulture in the air, but it is his keen sight which enables him to see the dying beast, and so to descend to the carcase at once. In his flight the vulture circles very high in the air, and is almost invisible in the sky. Further off upon the horizon another vulture is circling, and further on still another; so that when the first sees his comrade descend to the ground he immediately follows his track; another sees the departure of the second and follows him; and thus it is that in a few minutes after an animal has been shot, although not one vulture may be in sight at the time when the creature falls, the whole carcase is covered with numberless birds. [Cf. Kirk, Ibis, 1864, p. 22: Anderss. B. Dam. Ld., p. 3, &c., &c.] All the Vulturidæ are tropical or intertropical in their habitat; they are the scavengers of the hot countries in which they live, and are most useful in clearing away offal and other rubbish, which if left to taint the air might breed a pestilence. They are found both in the Old and New World, but only come very occasionally into the northern parts.

The second division of the Birds of Prey, which we may roughly call "Hawks," as distinguished from "Vultures" and "Owls," is by far the largest, and would contain all Eagles, Buzzards, Kites, Falcons, &c. I shall shortly have to show you the true Falcons; but intermediate between the hawks and the vultures is a small assemblage generally peculiar to South and Central America, which are called the Caracaras. They have the aspect of the more noble hawks, but with that they combine to a great extent the habits of the vultures. They live upon the ground, frequent marshes to a great extent, and feed largely upon reptiles and frogs. They are remarkable for having the toes of the feet joined together near the base by a continuous web. This is their great characteristic, and we cannot fail to see how useful such a support to the foot must be in birds which live in marshy ground. One striking example of these Caracaras is exhibited to us in the Secretary Bird of which you have an illustration before you. They are found only in Africa, inhabiting the greater part of the continent below the Sahara, and are protected both by the European governments and by the natives in whose country they occur, on account of their great utility in destroying venomous snakes; and to kill one of these birds is an offence punishable by a heavy fine. Sometimes, I regret to say, the birds do not get the best of the encounter. A correspondent of mine,

noticing a conflict between a snake and a secretary, was surprised to see the latter suddenly run to a pool of water and fall down dead. On examining the bird he found that the snake had managed to draw blood from the point of one of the pinions. I may add that the name "Secretary Bird" is supposed to be given to it on account of the long feathers which we see behind the head, which represent, so people say, the quills of a secretary when writing; but I must confess that I have never seen a secretary with so many quills behind his ear.

We will proceed now to an illustration of one of the nobler hawks. The bird we have before us is the white-shouldered Imperial Eagle, a native of Southern Europe. Now we are always accustomed to associate everything grand and noble with the eagle, but that is a very much exaggerated idea, as I can assure you; and if it were not for the fact that gamekeepers shoot all the eagles that make their appearance in England, we should have a better opportunity of studying their habits. Eagles are very little more than great buzzards, and there is nothing but their grand flight to inspire us with respect for their character. Now the Imperial Eagles, of which there are three species, grand as they look, are by no means such magnificent fellows as we should fancy from their appearance. Mr. Hume, a good observer, writing from India, calls one of these eagles a "great hulking kite," an "ignoble feeder," and says that he has plundered the nest of a pair of these great birds without their having flapped a pinion in its defence, or attempted to attack the intruder who robbed their nest.

I now show you one of the true falcons, the Greenland Falcon, a bird which very rarely comes over to England in winter. In Greenland it is by no means rare, though it is not so common as in former days. We learn that in the Middle Ages a present of a pair of these birds, from one monarch to another, was always considered a right royal gift. I cannot pass by this falcon without calling your attention to an instance ot protective colouring which is exhibited in the birds of Greenland. Of course that country is during the greater part of the year under snow. The Greenland Falcon, as represented in our picture, is preying upon the ptarmigan. The ptarmigan in summer is a very dark bird, almost black. Supposing that this black bird never changed its plumage, what chance would it stand against the hawk or the owl in the winter, when the whole ground is covered with snow, or in

the autumn, when the general mossy character of the country gives a grey tint to it? Why, in a minute it would be gobbled up by the birds of prey, because it would remain as a black speck in the midst of the snow. Therefore we have in these birds a wonderful provision of Nature, for we find that the ptarmigan changes its plumage with the season of the year. In summer it is black, the country being darkest at that time; in autumn it changes to a grey colour, so that it assimilates to the general mossy and grey colour of the country; while in winter, when the snow is all over the place, the colour of the ptarmigan is white. Thus we see an instance of the way in which the balance of Nature is preserved. Of course the same rule applies to the falcon and the snowy owl, which are also white, for if they were black they would have no chance of catching birds in a country covered with snow, where their dark forms would be easily seen approaching.

Now, after the diurnal birds of prey, or those that fly by day, we must turn to the nocturnal, or the birds of prey which fly by night. This is the general or popular division of the two groups, but it is not quite a correct one, because there are owls which fly entirely by day, while there are hawks which fly by night. But taking the two groups as a whole, it is a very fair division to divide them into diurnal and nocturnal birds of prey. The owls differ from the hawks in having the outer toe reversible—that is to say, they are able to turn it backwards or forwards as they please, and this gives them a very great purchase in capturing their prey. I am sorry to say that the general superstition caused by the melancholy notes and shrieks of the owl renders it an object of fear to most people in the countries it inhabits; but I hope that a kindlier spirit towards these much maligned birds will prevail, and that instead of seeing them nailed up as vermin in a "keeper's larder," they may be afforded that protection which they merit on account of their utility to the farmer in keeping down mice and rats. The illustration now before us represents the Great Eagle Owl *(Bubo ignavus)*. I hope that you will take my word for it that the owls are birds which ought to be protected and not killed, because of the amount of good that they do.

Well, after the birds of prey, I want to consider a very large order, which is generally known to present systematists as the Picarian Order of birds *(Picariæ)*. The characters on which this order is founded are chiefly osteological, and I need not trouble you with details, for which we have not the time, but I shall try to show

you in a more simple way the general characteristics of the group. They are divided into two large divisions, which may be called scansorial or climbing, and fissirostral or wide-mouthed birds. Now of the first the Woodpecker is a good example; of the second the Kingfisher or the Goatsucker; both of which I will show you presently. If you look at the foot, which is represented at the left-hand corner of the picture now before us, you will see that the toes are there placed two and two; not three in front and one behind, like the common sparrow or canary, or any familiar bird, but two and two in pairs; and this is the principal characteristic of the climbing birds. Then I show you here—that I need not refer to it when I come to the picture of the bird—the woodpecker's head. You see what a strong bill he has, and what a curious long tongue with little barbs at the end. Now of course the first question that occurs to us is, where does the woodpecker put his long tongue? He cannot keep it in his throat, as other birds do, because of its length. Well the nature of the woodpecker's tongue is thus explained: the tongue bones are produced backwards and curl over the back of the skull till they are inserted in the cavity of the right nostril, and these are furnished with muscles which enable it to dart out its tongue to the extreme length which we see here. At the same time the latter is furnished with a glutinous fluid to which the insects become attached, and are thus more easily secured. Of the climbing birds the most highly-developed perhaps are the Parrots, which by many zoologists are considered to form a separate order *(Psittaci).* Here we have an example of the common Grey Parrot, which we often see in cages; but here he is not represented on a perch or in a cage, but in his native forest. And I must tell you that Mr. Kevlemans, whose services I have been so fortunate as to secure for these pictures, has possessed the rare advantage of studying the birds in Western Africa, where of course the tropics have afforded him the opportunity of illustrating the birds in a state of nature, which could not have been done by an English artist who had never visited those parts. Now the grey parrot in the part of Africa which the artist visited—namely, Prince's Island—was a very common bird, and he has worked up its natural history, and written a good deal about it. There he found the parrots going in flocks in the forest. In the daytime they visit the maize-fields of the inhabitants, and do a great deal of damage. Within half a day's journey from Prince's Island is the island of St. Thomas; and although the conditions of the

two islands are very much the same, on St. Thomas there is not a single grey parrot to be found, but on that island the common Black Kite abounds. In Prince's Island the parrot is very common, and not a single kite is to be found there. The two birds seem as if by mutual consent to have selected these two islands as their respective habitations; and if by any chance an unlucky parrot is blown across to the island of St. Thomas the kites immediately assemble and make short work of it; and if a kite should by any chance wander to Prince's Island it is served the same by the parrots. Before passing from this order of birds I want to show you another kind of parrot, which is one of the most extraordinary of all. This is the Great Black Cockatoo, a very rare bird, only found in Northern Australia, New Guinea, and the adjacent islands. There is not much known of his habits, and I only show him to you as an extremely curious species. His bill is said to be so powerful that he is able to break with it a hard nut which it is impossible for a strong man to crack with a hammer.

We will proceed to another family of climbing birds, namely, the *Cuculidæ* or cuckoos. Speaking in the country I must not suppose that there is anyone in the room who does not know what this bird is, as it is an English bird; but in London I often ask the question, and I know that it has puzzled a good many people to tell me what it is. It is our common cuckoo, a bird more often heard than seen. I daresay some of you would like to know where the cuckoo goes when it leaves Europe. I can tell you for certain, having seen specimens from that locality, that the cuckoo goes right down Africa to the Cape of Good Hope; it also goes into India, and is not uncommon there during the cold season. Some people suppose that it even travels farther, and specimens are said to have been received from the island of Celebes, in the Moluccas. Now the cuckoo is a bird of such extraordinary habits that it would not be difficult for me to occupy the rest of the time this evening with stories concerning it; but time will not allow me to do more than draw attention to one or two facts in the natural history of the bird. You know that it never builds its own nest. It lays or places its eggs in the nests of other birds. Popular belief has always supposed that the cuckoo lays its eggs in the nests of the birds; but it is now a pretty well-known fact that the cuckoo does not do so, but lays its egg on the ground, takes it in its beak, and places it in the nest of the bird which it selects to be the foster-parent of its young. Now my own expe-

rience bears out the theory which has been brought forward by some good naturalists, that the egg of the cuckoo found in the nest of a bird is scarcely distinguishable from the eggs of that bird whose nest it selects. In Berkshire, where I have chiefly studied the cuckoo, the nest principally adopted by the bird is that of the water-wagtail; and I have been many times struck by the extreme resemblance of the cuckoo's egg to those of the water-wagtail—there seemed to be no difference except in size. Well, then, on the other hand, many cuckoos' eggs very much resemble the eggs of the lark, but are of a darker brown. The Germans, who pay much attention to the study of birds, and are very patient in their investigations, have recently written much on the subject, and one man has stated that sometimes the cuckoo lays perfectly blue eggs, which it deposits in the nest of the hedge-sparrow. The hedge-sparrow, as we know, is the generally-accredited foster-parent of the cuckoo; but never in my experience have I found a brown cuckoo's egg along with the blue eggs of the hedge-sparrow. I just throw these few hints out on a point to be studied by anybody interested in this subject, because it is a very remarkable thing if the cuckoo should lay dark eggs and place them in the nest of the hedge-sparrow. If so, it seems to me to dispose of the theory of the assimilative colouring of the eggs; or else we must believe that the hedge-sparrow is more stupid than most birds, and is not able to distinguish between its own eggs and those of the cuckoo. There are many other facts connected with the cuckoo, but time will not allow me to draw your attention to them.

Turning to the true *Picariæ*, we must first study the Tourakoes and Cuckoos, birds which Mr. Garrod would place in a different sub-class to all the others, as more closely allied to the *Gallinæ*. There is so much that is excellent and unanswerable in his arrangement of birds, that I regret to see that his studies lead him to place these birds so far from what I consider their natural position; and in this point I must follow Mr. Wallace. At the same time it must be remembered that Mr. Garrod gives exact characters for his classification; but I think that in this case those that he gives are not of the importance that he considers them, when weighed with others more significant, as to the real affinities of these two families. The tourakoes have two toes before and two behind, although it is not on record that they ever climb up trees or use their feet as parrots do. They are natives of Africa,

and, with the exception of two or three species out of the eighteen known, are remarkable for the red colour which we see depicted in the wing of the bird before us. I have been informed by a naturalist who has travelled much in South Africa that when a storm comes on, and this bird is caught in it, the colour is entirely washed out of the wing, and the feathers become white; and after two or three days the colour is renewed. We know that if we take a skin of this bird, and use soap and water, we are able without difficulty to wash out that red colour, and it immediately becomes quite white, while the water is stained red. An English chemist of repute, Professor Church, took some feathers of this bird and analysed them to find out the substance of which the red colour was composed; and he found that it was allied to copper—a new substance entirely—and he gave to it the name of turacine, from the name of the family. I do not know whether the story I have told you about the bird being enabled to renew the colour, in a state of nature, is true, but it seems highly improbable, and the damaged plume would most likely remain worn and faded until the next moult. In Africa, as well as the Himalayas, occur the honey-guides (*Indicatoridæ*); but the African species alone, as far as we know at present, are worthy of the popular designation. You must have heard or read of these little birds in the books of African travellers, how that, by incessant calling, they lead the hunter step by step to the bees' nest, and wait in the neighbourhood, patiently, until the honey is taken, when they descend for a portion of the comb, which is always left as the share of the "guide." I regret that I have not an illustration of this family to show you, nor of the next, the climbing barbets (*Capionidæ*). In structure and habits these two families form a very evident link between the cuckoos and the toucans; indeed one species of barbet, nearly the largest of all, has received the name of *Tetragonops rhamphastinus* on account of its general similarity to a Rhamphastos or toucan. The great bulk of the scansorial barbets are African and Indian, but there are also a fair quantity of species found in Tropical America. The picture now before us represents an example of the family of toucans which I mentioned just now. These are all natives of South America and Central America; nothing of the kind is found in the Old World. The curious position of the bird on the right represents the habitual manner in which these birds sleep, and although their bill looks so large and clumsy, it is in reality the lightest structure imaginable, being full of air cells.

The tongue is remarkable, extending the whole length of that long bill, and being of a horny character with a feathered tip.

Among the climbing birds of which I spoke just now, I showed you a specimen of the woodpecker's tongue. Here is an example of the great Spotted Woodpecker, by no means a rare bird in certain parts of England. I have nothing much to say about it, but you will observe by the illustration that the disposition of the toes is eminently typical of the group of climbing birds. I now want you to look at that long bill which is the lower figure in the picture, and the curious stout foot below it. They are the bill and foot of a kingfisher *(Alcedinidæ)*, which is one of the best examples of the wide-mouthed and flat-footed birds of the second division of the *Picariæ*. The outer and middle toes of the kingfisher are joined together for two thirds of their extent, so that it produces a very splayed sole to the foot, and this is one of their greatest peculiarities. We will now proceed to show you some of the birds themselves. The first that we have to speak to you about is an example of our common Kingfisher. I have not time to say anything very particular about the habits of this bird, although having written a book about the family I ought to be able to say a good deal; but I am afraid that if I began I should go on so long as to exhaust your patience. It is decidedly the brightest of our British birds, but is not equal to some foreign members of the same family inhabiting the tropical parts of Asia and Africa. Some of these do not feed at all on fish, but live entirely in the forests, where they chase insects. The shape of the kingfisher is not very striking as regards elegance—nothing like the beautiful and elegant forms of the insect-eating species, many of which have very long tails. But to a fish-catching species such an appendage would be very much in the way; and therefore, although our bird may be eclipsed in some respects by his more brilliant brethren of the tropics, we cannot but admire the admirable adaptation of his form to his requirements—the long bill to cleave the water in his downward plunge, and the tail not long enough to impede, but of sufficient dimensions to guide him as a rudder as he makes the stroke. Closely allied to the kingfishers are a little family of birds consisting of only four or five species, the Todies *(Todidæ)*. There is very little known about them. They are all inhabitants of the West Indian Islands, to which they are entirely confined; none are found on the continent of America itself. In their

habits they are more like flycatchers than kingfishers, although their anatomy connects them with the latter family. From the todies we will pass to the motmots (*Momotidæ*), another American family, remarkable, as you may see, for their racket tails. But a more curious fact is that the appearance of this tail is produced by the birds themselves. At first, of course, the two middle tail feathers are of the same length as the others when the tail is newly moulted; and I have seen several examples, probably of young birds, who, being inexperienced, have begun nibbling the wrong feather; and they have not known, till the middle one began to shoot out beyond the others, which was the one to begin on. It is an undoubted fact that these birds nibble away the web from the shaft, leaving it quite bare.

Another family of brilliant birds belonging to the same group are the Trogons (*Trogonidæ*). These birds are found in Central and South America, in Africa and tropical Asia. Unfortunately their brilliant plumage has made them very fashionable, and the result is that they are much in demand for ladies' hats, not so much in England as in Paris, and this has caused the almost entire destruction of some of these beautiful Trogons. This picture represents one of the most picturesque of the group. A few years ago it was by no means rare in the forests of Guatemala; but now I am informed that the Indians who hunt the bird have to travel 300 or 400 miles before they come to any forests containing any number of them.

The illustration now before us represents the European Bee-eater, the type of the family *Meropidæ*. As its name implies, the bird lives on bees and other *hymenoptera*, and is, therefore, very destructive to hives in certain parts of Southern Europe, where the bird occurs. Occasionally it wanders as far north as England, where it meets with (literally) a warm welcome, being at once shot and placed in a collection. This, I regret to say, is usually the case with rare visitants to this country; but the bee-eater finds a hard fate in other countries besides England, for in Morocco and certain other countries he is shot in numbers during migration and sent to adorn ladies' hats in London and Paris. Five hundred were consigned in one lot last year to England. When the bee-eater quits Europe, which he does during our winter, he betakes himself to the Cape, and in South Africa he rears another brood. Very few European birds do this; and it is a matter of

congratulation that this second brood probably replenishes the loss occasioned by the persecution of the species during its sojourn in Europe. Another closely-allied family, the Rollers (*Corociadæ*), must be alluded to here, though I have not an illustration to show you.

We have one of the most extraordinary looking examples of the fissirostral group in the Hornbills (*Bucerotidæ*). This gentleman is represented as performing a very curious act, one peculiar to the family. He is engaged in feeding his wife with some fruit, after having carefully boxed her up in a tree along with her egg. This curious habit of the hornbill has been proved to belong to the family wherever any have been found. Wallace, when travelling in the Malay Archipelago, found it was true of the Sumatran species. Livingstone long ago related it concerning the South African ones; and a little while ago I had a very curious confirmation of it with regard to some of the West African species. I had a collector on the West Coast of Africa, an old negro, one of the Fantees, for whom we went to fight. They have always been spoken of by our soldiers as a very despicable race. I never found that with this old negro; in fact, he was rather sharper than the rest of mankind, for when he sent me collections of these and other birds he had the knack of making them out to be worth something like £180, when he was glad to accept £25. I was so much struck with his individual acuteness that I begged him to give me a little of his experience about the birds which he shot. One day he sent me an old female hornbill and a young one, which he had cut out of a hole in a tree; and this is his story of the bird, told in his own words: "When the female go to sit, the male he her shut in tree. If he no bring food, then she angry. If he no then bring food, then she more angry—swear. If he no then bring food, then she curse him for die. Man—beef—beefy—beef!" I never could make out what the last part meant—whether it was really the cry of the hornbill, who perhaps having lived under British protection on the West Coast of Africa had learned to speak English; or whether it was the negro's best imitation of the cry of the enraged and starving hen bird. However that may be, there is not in the whole range of ornithology a more curious fact than that of the male hornbill shutting up the female during the nesting season, nor one apparently more inexplicable, as the exertions of the male bird to supply the hen with food reduce him to the utmost

ditsress; nor is the female, when liberated, in a more prosperous condition. The emaciation of the male is comprehensible, as Dr. Murie has shown that the envelope in which the food is contained is actually composed of the epithelial lining of the bird's stomach.

Closely allied to the Hornbills are the Hoopoes (*Upupidæ*), of which this is an example. The Hoopoes, by reason of their sandy colour, might be known almost certainly to be inhabitants of a desert region. There is, no doubt, much scope for study in the assimilative colouring of the plumage of birds to the different countries which they inhabit. I gave you an instance of it just now in the white falcon and the birds of Greenland. Here we have an instance of a sandy-coloured bird which is chiefly a frequenter of sandy and arid localities. It is said that this sandy colour is a great protection to the hoopoe, for on seeing a hawk he is sharp enough to throw himself flat on the ground, turn his wings round, stick up his bill in the air, so as to look as much as possible like a bit of old rag.

Before leaving this group we have to consider three other families, one of which, the Goatsuckers (*Caprimulgidæ*), of which the bird before us is an example, have the widest gape. Anyone who has examined a goatsucker must have been struck with its enormous mouth, and still more by the extraordinary long stiff bristles which are found on either side of the mouth. The use of these bristles has been variously estimated. By some people it has been said that they are of use to the bird in guiding the moths and small insects, on which it feeds in the dusk of the evening, into its mouth. I think there is another explanation of it, and that is found in the curious comb which is attached to the middle toe of the bird's foot: this is doubtless used in scratching the ground, and I fancy there is some connection between this toe of the goatsucker and the bristles, because by constant scratching this comb-like appendage must become very much clogged, and the stiff bristles would be of use in cleaning it. At all events I cannot see the slightest reason for their being required to catch moths, because if the creature's mouth is not large enough to catch a moth, no amount of bristles would ever help them in.

The last two families of Picarian birds are the Swifts (*Cypselidæ*) and the Humming-birds (*Trochilidæ*). They form, in the opinion of some naturalists, a distinct order (*Macrochires*). Of the first of

these families the common swift is a typical example, and this is the bird in our picture. It only visits us during the summer. It may interest you to know the winter home of the swifts. Like the cuckoo, this bird, when it leaves our shores, goes, principally by the route of the Nile valley, down to the Cape of Good Hope.

I need hardly tell you that the little Humming-bird now before us is magnified many times above its natural size, because the bird is not in reality much larger than our finger. The humming-birds are entirely natives of America. Some few species manage to get up into North America and one occurs even in Canada in the summer; but the bulk, consisting of about 500 different kinds, are only found in Central and South America. Some of them are very rare; all are very beautiful. The present one is unfortunately, I am sorry to say, a favourite with the ladies for their hats. He is brought in immense numbers to this country. Not long ago I heard of 30,000 skins being sold by auction for 2½d. each, for plumes, so that it will not be long before this will be one of the rarest of the hummers. Of one of these humming-birds only one specimen is known, and I know a gentleman who has offered £50 for a specimen of one of these birds, and has not been able to get it. A friend of mine when travelling from Peru down the Amazon saw the tail of one of these rare humming-birds in the head-dress of an Indian chief; but beyond a single specimen in an English collection there is not another known; so that although some hummers are common, you will see that others are extremely rare.

We now come to the great order of Passeres or Perching Birds, of which I can only show you a few striking examples, to illustrate some of the principal families. Among the most aberrant of all the order may be mentioned the Ground Thrushes (*Pittidæ*). You will see in the bird before you one remarkable for the varied tints of its colouring, and for its squat form. The members of this family are found only in the Old World, the greater number of species occurring in the Malay Archipelago, but they are also found in Australia and the Indian peninsula. One species has been obtained in China, and one is also found in the forests of Western Africa. I must tell you that the exact place of *Pitta* in the natural system is not yet satisfactorily determined; but it will probably be found to have intimate relations with certain American families of ground-loving birds, such as the *Pteroptochidæ*, *Formicariidæ*, &c. We must pass by several families of birds in

rapid, succession—the Tyrant birds (*Tyrannidæ*), Chatterers, (*Cotingidæ*, *Pipridæ*). But before quitting this group of Passerine birds I will shew you two very striking chatterers. In America this family is largely represented, and one of the most curious of them is the Bell-bird. There are three species, and all have these curious ornamental appendages on the head. There is no doubt that the bird is able to raise and deflect these appendages, the purpose of which is doubtless ornamentation. Among the chatterers this is one of the most peculiar—the Cock of the Rock (*Rupicola crocea*). This is also an American genus. Three species are known—a yellow one in Demerara (this present one), and two blood-red, found in Ecuador and Peru. Little has been recorded of their habits.

The birds which we have just been considering, though remarkable for brilliant plumage, are not celebrated for their vocal powers; and it is a well-known fact that the birds of the tropics cannot rival our own plain-coloured species in the matter of song. The larger number of the families which I shall now introduce to your notice contain good songsters. First of all, then, come the true Thrushes (*Turdidæ*), and there can scarcely be a bird more familiar to you than our common Thrush. I have, therefore, here chosen the Redwing as an illustration of the family. It is a well-known winter visitor to this country, and though it does not sing much when it is here, when he returns to Norway, where he breeds, he has a very decent song, though by no means so good as that of the common thrush. Here is another instance of a dull-coloured thrush, which has its dullness of plumage compensated by one of the most beautiful songs in the world. It is an American Mocking Bird (*Mimus*). The mocking birds form a little genus peculiar to America, and they are found from the north to the south of that continent; and not only do they possess good songs of their own, but they are also capital mimics; hence their name, and very celebrated they are for their wonderful powers.

No better instance of the fact which I have mentioned above could be found than in our English Nightingale (*Daulias luscinia*). I am sorry that Manchester is so far north, that you do not get nightingales to come up here; but I am sure if they did you would appreciate them a great deal better than we used to do in London, for if ever there was need of protection by Act of Parliament, it was for the nightingales. I assure you that in the Highgate and Barnet Woods, to the north of London, the nightingale is very

plentiful on his arrival. I have heard five or six myself this summer singing at once, and very glad I was to hear them, and to think that Parliament had interfered to protect these beautiful songsters. Before that Act was passed I have known to be brought to one shop in the north of London, 300 cock nightingales, all singing birds, which had been caught within three weeks of their first arrival in this country. I think you will agree with me that it was time something should be done to protect them from the bird-catchers. Perhaps you do not know where the nightingale goes in winter. I did not know until after the late war in Africa. That was one of the benefits which accrued to science from that war. It taught us where the nightingale went in winter, for it was found by one of our officers in the forests of Ashantee. Before that we always thought they went to Algeria; now we know they go right across the Sahara to the forests of the West Coast.

After the warblers comes a little family of birds very widely spread over the world, the Creepers (*Certhiidæ*). We have one illustration of that family in England, the little common creeper; but the one I have chosen to show you to-night is the most beautiful of the family, the Wall Creeper (*Tichodroma muraria*). This bird is found on the Alps and the mountains of Southern Europe, stretching across Turkey and Asia as far as the North-west Provinces of India. His habits are very much the same as those of our little creeper, only he frequents the rocks and walls instead of trees.

I dare say the next little bird is familiar to many of you. I have chosen him as an example of the family of Titmice (*Paridæ*). It is our little English Bottle Titmouse, and he is a remarkable bird in more ways than one. I dare say few of you know that he is one of the small number of birds which are peculiar to the British Islands. That fact has been ignored or overlooked by many naturalists till I pointed it out a few years ago—that our common little bottle titmouse is quite a different bird from the bottle tit of the Continent, which has a pure white head in both male and female. I have had great difficulty in getting this fact recognised, although I have numbers of specimens to prove it. I have shown it to many Continental naturalists, who at once see the difference; but English naturalists seem chary of giving up a belief which has been impressed upon them in everyone of their books for years, however erroneous the fact may be. I can assure you that if you would only take the trouble to get specimens of

the little titmouse from the Continent you would see that it was a very different looking bird, and really the difference is what we ought to expect. We do not know how long the British Islands have been separated from the Continent, and we *expect* to find different birds in the islands lying off America, or any other continent, to those found upon that Continent; but because this suggestion has been made with regard to European birds there is great difficulty in believing it. Now all our resident birds are more or less different from those on the Continent, and it would be wonderful if, with our moist climate and separation from the Continent, it were not so. They not only differ in plumage, but many of their habits are quite different, and some day I hope to recount to you some of the researches I have made into this subject.

After the Titmice we come to a very powerful family of birds, the Shrikes or Butcher Birds *(Laniidæ)*. We have one little species which comes over to England from South Africa in the summer, and in the winter we are visited by the great grey shrike, which is the species before us. The habits of all these birds are the same; they catch insects, impale them on thorns and leave them to get a little decomposed before they commence to eat them. They don't at all mind eating small birds, as well as beetles and other insects; and a shrike's larder, which some of you may have seen, is often a conglomeration of festering and decaying insects.

After the shrikes we have the Flycatchers *(Muscicapidæ)*. I do not select as an illustration our common brown Flycatcher, as it is a very plain bird, but show you one more beautiful, the Paradise Flycatcher of India. Of course, as I told you before, a bird living in the tropics, with such a brilliant plumage, is not likely to sing, and this bird does not; but he is very beautiful as regards his plumage and long white tail. We have an illustration here of the family of Orioles *(Oriolïidæ)*, in the Golden Oriole, a bird which is plentiful in most parts of Europe during the summer, and migrates in winter down the Nile valley to the Cape of Good Hope. It occasionally visits this country; several of them have been seen of late years in the Scilly Islands, off the coast of Cornwall.

Here we have an illustration of the Birds of Paradise (*Paradiseidæ*). This one before us is by no means the most striking of that gaudy family, but it is sufficiently curious to show you somewhat of the

way in which all these birds are decorated. There is not one of them but what is ornamented with long plumes in some fantastic fashion. This is the King Bird of Paradise. All the members of this family are only found in New Guinea, or in the islands of the Malay Archipelago. I have no doubt that if the Government accedes to the request of the people of Australia, and annexes New Guinea, we shall be able to find a good many new kinds of birds of paradise; and I should not wonder if it was some naturalist who put the Australian Government up to the idea of annexing it for that purpose!

We now come to consider the family of Crows (*Corvidæ*). You all know what the old black rook is, and I have not brought an illustration of the Rook or Crow, because they are quite black, and very uninteresting in appearance; but I show you the Magpie and the Jay, which are two of our handsomest British species. Both the jays and the magpies are typical northern forms, the latter being found over the whole of Europe and Northern Asia, several species being met with in the Himalayas. The Jays have the same distribution as the magpies; but in America, where magpies occur, no typical Jays are met with, but they are replaced by more brilliantly coloured species, whose general aspect is blue.

I have not brought an illustration of our common starling, because it is such a well-known bird; but, as a representative of the family of Starlings (*Sturnidæ*), I introduce to you a Glossy Thrush. All these birds are found in Africa, and they have the manners of our own starling—going in flocks, and having a harsh chattering note—but they are more brilliantly coloured than our own bird. I shall show next a remarkable kind of starling, and one of which it will be difficult to see a specimen in a few years. The bird now before us is the fast-expiring Huia Bird of New Zealand. I draw your attention to the very curious difference in the bills of these two specimens before us. One, you see, has a very long curved bill; the other a short stout one. The latter is the male; the one with the curved bill is the female. The natives of New Zealand have an anecdote respecting these birds. They say they always hunt in the forests in company, and the male, with his strong bill, knocks off the bark and discovers a grub underneath, and the female takes the grub out.

The bird now before us is one of the Hang-nests (*Icteridæ*), and the family which it represents is intermediate between the Starlings and the Weaver Birds (*Ploceidæ*). Indeed the nest that

it builds is very similar to the structure of the latter family. If any ladies fancy that they are good hands at tying a knot, I can assure them that this little weaver which we now see before us can teach them a lesson even in that. If any of you ever come to the British Museum, and will take the trouble to visit the "Nest Room," you will see some very striking examples of the weaver-birds' work, and you will agree that they weave their nests in the most wonderful manner. The nests are five or six times the size of the birds, who build in companies on trees. It is said that they are so attached to the art of weaving that even when a pair have completed their nest, and the hen bird is sitting, the male bird cannot keep from weaving, but makes himself a little bower, with a branch across it, where he perches, and sings to the female while she sits.

I shall complete this hasty sketch of the great order of perching birds by showing you an illustration of two Finches (*Fringillidæ*). These may be taken as typical examples of the conical-billed section of the Passeres, the characters of which I just now showed you in contrast to a thin-billed bird. The first is a Chaffinch, the most typical of all finches; and the second example of the family which I propose to show you will be the Crossbill, and the legend which is connected with the crossed mandibles and blood-red colour of this bird you will perhaps allow me to introduce to you in the words of the poet Longfellow :—

THE LEGEND OF THE CROSS BILL.

(*From the German of Julius Mosen.*)

On the Cross the dying Saviour
  Heavenward lifts his eyelids calm,
Feels, but scarcely feels, a trembling
  In his pierced and bleeding palm.

And by all the world forsaken,
  Sees he how with zealous care
At the ruthless nail of iron
  A little bird is striving there.

Stained with blood, and never tiring,
  With its beak it doth not cease :
From the cross 'twould free the Saviour,
  Its Creator's Son release.

And the Saviour speaks in mildness:
"Blest be thou of all the good!
Bear, as token of this moment,
Marks of blood and holy rood!"

And that bird is called the crossbill;
Covered all with blood so clear,
In the groves of pine it singeth
Songs, like legends, strange to hear.

We must now pass to the next order, the Gallinæ, including the Doves and Game Birds, and the characteristics of these two groups are now shown in the accompanying slide. Here you have an illustration of the ordinary Wood Pigeon's head and that of a common fowl. As an example of a typical pigeon I have shown a picture of our ordinary English Ringdove or Wood Pigeon; and, as an aberrant member of the family, one of the Crowned Pigeon, a native of the Molucca Islands—it may be seen in the Zoological Gardens of London and on the Continent. The bird is ornamented with a tuft of pretty little feathers, which has earned for him the vernacular name he bears.

The next illustration will show you that interesting extinct bird the Dodo, formerly inhabiting the Island of Mauritius. In the island of Samoa, in the Pacific, there is a pigeon which is very rare, but now that several specimens have been obtained, its anatomy has been carefully worked out, and it is considered to be the nearest ally of the Dodo: it is called the Tooth-billed Pigeon (*Didunculus*), and, as you see, is rather a finely-coloured bird. I cannot say much for the beauty of the Dodo, but a certain amount of interest attaches to this bird, which was living about two hundred years ago, but has now disappeared from the face of the earth. The range of the Dodo was very restricted. It was only found in the south-west corner of the Island of Mauritius, and when the island was colonised the bird soon became extinct. The sailors are said to have killed a great many of them for the sake of their breast bones to sharpen their knives upon. There is a tolerably perfect skeleton of the bird in the British Museum, but all existing specimens of the bird have long since disappeared.

The game birds have several very well marked families, as the Grouse, Pheasants, Partridges, &c. Here is an illustration of a Grouse, a family which is chiefly found in the northern parts of Europe and America. This is the largest of the family, the Cock of the Woods, or Capercailzie.

I will now show you the Monâl, or Himalayan Pheasant, which is one of the most beautiful of all the family. This is the male bird. The female is brown, and has none of the metallic plumage of its mate : indeed the females of nearly all the game birds are plainly coloured in comparison with the males.

This is a remarkably fine-looking Pheasant. It is the only specimen that has arrived in Europe, and the unique example is at present in the British Museum. It is called Buliver's Pheasant, or the Lobed Pheasant, on account of the blue lobes which ornament its head. It comes from the Lawas Mountains, in the northern part of Borneo, a part in which no European has ever set foot. It is one of the most startling birds we have seen for many years, not only on account of its beautiful plumage, but because of its structure and the number of its tail-feathers, which exceed in number those of any other game bird known. It is surprising that such a beautiful bird should have remained so long undiscovered, and I was glad to get such an interesting addition for the national collection.

The bird now before us is the Great Bustard, a bird which once was pretty common in England, but civilisation has drained the marshes it frequented. During the French and German war we had nearly a dozen Bustards whose capture was recorded in England. It was supposed by some that the cannonading of the contending armies frightened these birds from their accustomed haunts over to this country; but they were all killed, and no attempt was made to reintroduce this bird.

We shall now pass to the consideration of a large group, popularly known as Wading Birds. These are remarkable, as a rule, for their long legs, which enable them to wade in the water. Although the order (*Gralliæ*) has been of late divided into several divisions, which seem to me well characterised, I have no time left to dilate upon these different sections ; but I can, in the few moments remaining to me, do no more than show you some of the most peculiar forms. One of the most beautiful of the Cranes is now before us, namely, the Crowned Crane, a native of Africa. The next bird is the Shoe-bill, also peculiar to Africa, where it was discovered by Consul Petherick, who procured the species in the upper districts of the Nile. Next we have the ordinary White Stork, which occasionally comes over to England. In Holland and other parts of Europe they breed on the houses, and are held in great respect by the people, who are very careful not to molest or injure them.

The present illustration represents the Spoon-bill, a bird which used to be plentiful in certain parts of England before the destruction of its haunts through the progress of civilisation. It is still found in some numbers in Holland and in Southern Europe.

Then we have a family of Rails (*Rallidæ*), which are remarkable for their thin bodies, long legs, and elongated toes. They live in the rushes and reeds by the side of water, and the thin make of their bodies enables them to penetrate the reeds with ease. This bird is a Jacana, and it is able to walk upon the leaves of water lilies with his long thin toes. The specimen before us is the Madagascar *Parra*, and the group he represents is found in India, Africa, and South America.

In accordance with modern classification, I have here to show you a Flamingo, as a representative of the family *Phœnicopteridæ*. Although we have no member of the family in England, they are very plentiful in Southern Europe, and indeed throughout the tropical portions of the Old and New World.

As an example of the great family of Snipes, we have an illustration of the Woodcock, and of the rest of the large group of the *Limicolæ*, the Plover and a Gull are representatives. To exemplify the Swimming-Birds, I pass in succession before you the Paradise Duck of New Zealand, remarkable for the striking difference in the sexes, where the female is as handsome as the male. The Swan, the Pelican, a Darter, and a Frigate bird come next; and lastly, we have a Penguin and a Great Auk, the latter once plentiful in certain parts of England, but now, unhappily, extinct. I cannot conclude my present discourse without bringing before you some illustrations of the flightless birds, of which the Ostrich is one of the most typical examples. The bird before us at present is a Cassowary, and Sidney Smith's couplet—

If I were a cassowary on the plains of Timbuctoo,
And I met a missionary, I'd eat him, and his hymn-book, too!

will doubtless occur to many of you. However clever this may be as a specimen of his powers in joining together uncouth words in a witty couplet, it unfortunately fails in giving an indication of the exact habitat of the genus *Casuarius*, which is only found in Northern Australia and the adjacent Papuan Islands. Of all the flightless birds there is none more remarkable than the Apteryx of New Zealand, with which I close my illustrations to-night.

As I stated at the outset of my lecture, I have not attempted to bring before you any new scientific arrangement, nor have I entered into details of the classification of birds. A systematist would easily find fault with the order in which I have introduced them to your notice, but I may fairly hope that in the short space of time allotted to me, aided by the talented pencil of my friend Mr. Keulemans, I have, in a comprehensible though unscientific method, introduced to your notice some of the most interesting representatives of the Birds of the Globe.

THE GREAT EXTINCT QUADRUPEDS.

A LECTURE delivered in the Hulme Town Hall, Manchester, on Wednesday, November 17, 1875.

BY PROFESSOR P. MARTIN DUNCAN, M.B. (LOND.), F.R.S.,

Vice-President of the Geological Society.

HEN men became sufficiently civilised to form themselves into nations, they soon began to encroach upon their neighbours for the sake of conquest, and to travel into distant countries for the sake of commerce. In doing this they became acquainted with a very simple fact in natural history; and that is that different kinds of animals roam over different countries—or in other words, that every country has some animals which are peculiar to itself. Thus the Chaldeans and Assyrians in the early days of civilisation wandered into India, and there they saw the elephant and the tiger and the long-tailed monkeys; but they missed the camel with two humps on his back and the wild ass and the goats of their native land. When for the sake of conquest they pushed onwards into Syria and Egypt, they came across the long-necked cameleopard and saw the hippopotamus. They therefore became very early in the world's history acquainted with the simple fact that different countries have different animals in them. But the fact did not appear to be of very great importance, because there were always some animals which roamed throughout all these districts—the lion, for instance, was found in Africa, in the land of the Assyrians themselves, and in India.

But as the world grew older, and as knowledge increased, it became evident that this simple principle was of some importance, for the application of it became world-wide. Thus after Columbus discovered America, the Spaniards, the English, and other races that attempted to conquer and to colonise North and South America, found that the northern part of the continent possessed animals of a different kind to those of the southern part. And, after that, when the colonists, and other people who went against their will, to New South Wales or Australia, found that they were living in, as it were, a perfectly new world of animals—that all

the animals with which they were familiar in America and Europe were absent, and that totally different kinds were there. Thus the old fact became worthy of consideration; and it was then seen that the meaning of the word "country" must be somewhat modified. These animals are not restricted or kept within certain limits which have a political significance, but they are restricted and separated from others by natural barriers. Each of these so-called countries, then, is separated from others by seas or high mountains and tablelands, or by deep and wide rivers, or sometimes by deserts. These districts are called, in the language of science, "natural history provinces." In consequence of the increase of this knowledge, the world may now be parcelled out into a number of districts, each of which has its peculiar animals, and which are not found anywhere else. The districts are called "natural history provinces," and the peculiar animals of each district are called "characteristic." The word characteristic means "not found anywhere else." Whilst this knowledge was gradually being obtained, huge skeletons, great skulls and teeth, and gigantic bones were being found underneath the soil in different parts of the world, in old river gravel, old lake beds, and in caves. The bones were so huge sometimes, that in the first instance they were thought to be the remains of giants; but as the science of comparative anatomy, which investigates the structure of animals and compares them one with another, was more studied, it became evident that these great bones belonged to animals and not to men; and there was no great difficulty in making two great divisions so far as these bones were concerned. The most gigantic of these remains were, as a whole, unlike those of any creatures now living—they belonged to kinds or species of creatures which are said to be "extinct," which once roved over the globe, but which live no longer. But a great many of the smaller bones resembled those of the modern creatures, which still exist and roam over the globe. So that in the olden time there were creatures living, some of which have descended generation after generation to the present day, and others which have died out.

Now, in pursuing this branch of science, it was found that every kind of great extinct animal did not formerly roam all over the globe, but that particular districts had some peculiar to them. These are the very same countries or provinces of which I have already spoken. In other words, in the olden time there were natural history provinces which correspond to the present natural history provinces of the globe, and there were gigantic animals

living in these provinces as well as some kinds that exist at the present time. Now, if I have made this clear to you, and you will think about it a little, you will see that there is some philosophy in it. For if you have a surface of land encircled by mountains, and perhaps a great ocean, and peopled by peculiar animals at the present day, and if there are to be found underneath its soil the remains of the modern kinds as well as those of gigantic extinct animals which are not found elsewhere, it tends to prove that the age of that province is very considerable; or, in other words, that whilst animals have lived and died out the geography of the surrounding district has remained very much the same.

In introducing the subject of my lecture to you it is absolutely necessary to try and vivify these old bones, because were I to lecture to you only upon the bones of the extinct quardrapeds, in about a quarter of an hour you would all be tired to death; but by placing these great extinct creatures in association with the creatures which are now living on the surface of the globe and their surrounding geography, perhaps the matter may be made interesting to you. At any rate, when you reflect upon what I tell you, it may suggest very important thoughts to your minds.

Now, let us consider first of all what we mean by a "characteristic animal." It is an animal, or bird, or anything alive which cannot get out of its particular neigbourhood. Let us take, for instance, the ostrich. It is a bird with a very long neck, a small head, rather a large-sized body, very long legs, and longish toes which are not webbed, and on looking at the front of the body there is just the vestige of a wing. You are aware that the ostrich does not fly, and that its feathers do not resemble those of birds which do fly. You are also aware that it has great side bones, to which are attached muscles which move the legs with great power. Thus the ostrich, being a tall bird, can scamper over the plains, and jump and move with great facility, but it cannot fly. Its roaming powers therefore are very restricted. It is stopped by high chains of mountains, and it is stopped by a large river, or the sea, for it cannot swim. Therefore the chances are that if the ostrich finds itself in a district where it obtains plenty of food, unless the district is an endless one, it will be very much restricted in its roaming, that is to say, in its distribution over the globe. I have instanced the ostrich because it represents wingless birds, of which there are a great many on the surface of the globe, there being different kinds in nearly every natural history province. To take another example from the ordinary monkeys with which you

are familiar. Very few monkeys can swim at all, and they cannot take long journeys on foot; they cannot fly—some of them cannot ever leave one particular forest; and therefore you will readily understand how they would be restricted by Nature to inhabit a particular spot. On the other hand, there are animals like the horse, which can pass over a great surface of ground, jump, and swim, and their roaming powers are great. But still the horse cannot climb over icy mountains or swim over seas of considerable breadth. Therefore the horse may be a characteristic animal, if the conditions and nature of the land and water around it are sufficient to keep it within certain bounds.

There are several natural history provinces on the surface of the globe, and to-night I shall only pay attention to those which give the best examples. They are in the southern part of the world where the influence of man has not been very greatly felt. Man, as you know, is the great troubler of the arrangements of Nature, in doing away with all sorts of barriers by which he allows creatures to commingle which formerly did not do so. So we will consider the three great natural history provinces of New Zealand, Australia, and South America. We will consider the relations of the great extinct quadrupeds and birds of those provinces to the present kinds of animals which live upon them, and also to the geographical changes of the earth which have affected them. When the first colonists went to New Zealand they found that there were no four-footed animals there; and, indeed, all the four-footed animals which are there now have been introduced either by the natives or by the emigrants. They found, however, a great number of birds; and one particular kind, very peculiar in its shape, was at once said to be characteristic of the province. New Zealand is surrounded by sea, it is a long way off all land, and it could only be birds of flight that could possibly move out of it and into it. All birds which cannot fly, and which once find themselves there, will of necessity remain. The first colonists found an interesting little bird there, which was about a foot in height, and whose feathers looked much more like hairs than those of common birds that fly. It had no wings and could not fly, a longish bill, a small head, and long legs, and toes which were not webbed. At a glance, then, it was a kind of diminutive ostrich; but it did not usually stand upright after the fashion of the ostrich, but crept along under the ferns and amongst the plants, and scrambled over the ground, as it were, instead of walked. Well, this little bird was called the wingless bird, or apteryx. Shortly afterwards a son of

the great English geologist, Dr. Mantel, who was examining the old soils, bogs, and river gravel of the northern island of New Zealand, came across some very gigantic bones, and they were sent over to England to Professor Owen for examination. The bones were extremely long, and were jointed on to something like the side bone of a gigantic fowl, and there were toes to them. The resemblance of these leg and side bones to those of the ostrich was sufficient to indicate that they belonged to gigantic birds. Professor Owen years ago restored these bones, that is to say he drew a figure of what he believed this bird was like from the few bones he then had. We have, then, a huge bird ten feet or more in height, but possessing all the peculiarities of the little apteryx; at any rate it resembles that bird more than it does the ostrich. As years elapsed some fourteen different kinds of these great birds have been found in New Zealand. Amongst their bones were also the remains of four kinds of the little apteryx. There were also discovered the bones of gigantic penguins and other birds which could move about and get out of the island. But evidently these huge birds first mentioned, which were called dinornis, or mighty birds, could not fly, for their wing bones were very small, and, therefore, were restricted to the former province of New Zealand. The interest of this fact has been increased of late by the discovery that the last of these great birds, under the name of the moa, were destroyed by the present aborigines or natives, for their bones were found burned, and close beside native implements. But, nevertheless, the fact remains that there were gigantic birds in the olden time in New Zealand, which greatly resembled the little apteryx, and more so than any other animal; and they were found in the same natural history province. But it is exceedingly difficult to believe that so great a number of kinds of these large birds could have lived on the present restricted surface of New Zealand. We are bound, then, to believe that formerly the natural history province was greater in extent, but still not sufficiently large to come very near any other land, because no other animals have been found in these islands, and the dinoris has not been discovered elsewhere. Singularly enough the river fish of New Zealand are, more or less, South American in their look. They resemble the fish of South America more than those of Australia; and this points to a former connection between the American and the New Zealand provinces. It is sufficiently probable that a great continent, or a number of islands close together, once existed which continued New Zealand, as it were, towards South America. The greater part of that

continent has disappeared completely under water, the coral islands which top the highest of some of the old hills now submerged being monuments of the old land. Now this dinornis has not been found in South America, and it has not been found in Australia, which is the nearest land. So, you see, we have here a very fair evidence of a natural history province of the old time being carried down to the present, and the extinct animals were thus mixed up with the kinds of the creatures which now exist. Doubtless it was the destruction of the great surface, and the limitation of the roaming grounds, which killed these gigantic birds by depriving them of their food.

And now to consider Australia as the next province. The Australian province is the most remarkable and the most simple of all those which contain four-footed animals. The map will show to you how this country is surrounded on all sides by the sea; but we must associate certain islands to the north of Australia with it, because they contain the same kinds of animals. These are the islands of New Guinea and those which are called the Negrito Islands. There is a little strait of some 12 miles across, the Strait of Lombok, as it is called, which is at the end of one of the long islands of the Indian Ocean (Java and Baily). This little strait separates the Australian province from the great province of Asia, to the north of it, and its importance was noticed by Mr. Wallace many years ago. He explained that, whilst to the north of this strait there were the monkeys, elephants, tigers, rats, cats, dogs, and the animals with which we are familiar in Asia and Europe; to the south of this 12 miles of water there is a perfectly new world of animals—barely one of the Asiatic kinds being found there. To the south of that strait, called now Wallace's Line, with one or two exceptions all the animals are what are called "pouched" animals (marsupial animals, from *marsupium*—a pouch), and belong to the kangaroo tribes. The animals of Asia are not found there, except one or two bats, and, probably, a kind of rat which got there by accident; and therefore the creatures covering this great island belong to a totally different group or order of animals. On the other hand none of these kangaroos, or pouched animals, are found to the north of this line. One of the strange parts of this story is that whilst totally different kinds of animals act the parts of flesh-eaters, insect-eaters, and gnawers of roots, in Asia and Europe, one great order of animals does all this in Australia. They are all kangarooish. Whether flesh-eating creatures, burrowers

eaters of roots, climbers of trees, or flyers, they would all be grouped by the naturalist as pouched animals. Now this distinction between the animals to the north and south of the strait is very simple, and it is kept up and produced at the present time by these 12 miles of sea and a tolerably rapid current. The order of marsupials or pouched animals to which the kangaroos especially belong, is therefore characteristic of the Australian province, and the common kangaroo, so well known in the Zoological Gardens, may be taken as the example of the whole of them. It has a kind of little bag in the under part of the body, into which its young go and take refuge up to a certain age. This bag or pouch is a kind of portable nursery, and in order that it may not press too heavily upon the creature in jumping, or running, it is supported by two bones in the muscles of the belly, which spring from the lower girdle of the body. These are called marsupial or pouch bones. The male has them also, and therefore they are not entirely for the purpose of supporting the muscles; but still their existence is enough to satisfy the anatomist that he is examining one of the set. Therefore, when any animals are found with these bones attached to them, you have a right to infer that they belonged to modern or ancient pouch-bearing animals. Besides this, the lower jaw has an inward bend behind, which is almost peculiar to these animals. Now the ordinary kangaroo represents the oxen o Asia and Europe—it is a leaf and grass feeder Then there is the wombat, which is also a pouched animal, and is more or less of a burrower and gnawer. Then there is what the colonists call the "native devil," which is a carnivorous kangaroo. One kind, called the petaurus, has the skin expanded between the arms and thighs, and is enabled to fly a little, so as to resemble in its mode of life a kind of bat. Then there are one or two tree kangaroos, which hang on by their tails, and others which lead a very quiet life, feeding on buds and shoots, and finally one land kangaroo, with a wonderful set of teeth, is an insect eater. Notwithstanding all these methods of living, there is in all these creatures the peculiar structures by which they are known to be Australian and marsupial. The long-legged and wingless birds of the province are characteristic and peculiar. No apteryx has been found; but one kind of emu lives in the east and another in the west of the island, whilst several cassowaries inhabit the north and the islands south of Wallace's Line—none of these are found elsewhere.

When the southern provinces of Australia were first surveyed, especially by Governor Mitchell, some huge bones were found in

the caves of the Wellington Valley, and when they were examined it was found that they resembled those of the marsupial order and no others. Some of the old kangaroos were very gigantic, both as regards their limbs and their bodies generally; but still there was no difficulty in saying that some of them belonged to kinds now extinct, and which fed upon grass, and to some which gnawed, after the manner of the common wombat; whilst there was also found a doubtful extinct flesh-eater, and one or two other animals that had the pouch bones and peculiar jaws, but were unlike the ordinary kangaroo in their bodies and limbs. All the extinct kinds resembled the modern ones more or less, and not those of other countries or provinces. Take, for instance, this large skull of Diprotodon, some three feet in length. It has a very small brain case, and a very deep jaw, and the front teeth are huge in the extreme. In the top and lower jaw, and in the ordinary crushing teeth, it greatly resembles the ordinary kangaroo. This gigantic creature had a skull resembling somewhat that of the kangaroo and wombat, although the limbs resembled those of the elephant, but there was more power of motion than it has in the fore legs. Instead of having short front legs and long hind ones, like the kangaroo, this creature had long front legs, so that all the extremities were equal. It did not hop or climb, but was a slow-moving elephant-like kangaroo, living on bark, leaves, or grass, and yet having a pouch for its young, and fore limbs so made as to enable it to attend to the little ones in its portable nursery. Another skull, you will observe, is ugly in appearance, very formidable looking, and very large, having much the appearance of one of the European beasts of prey. But there is a peculiarity about its lower jaw which is characteristic of the kangaroos; and we have reason to believe that it belonged to the kangaroo tribe and to no other. The teeth are very remarkable. You will observe that on either side there are two great projecting sharp front teeth; and these are followed by a tooth which is about three inches in length and exceedingly sharp. Then come two little tiny teeth which evidently were not used by the animal. In the upper jaw there was a great tooth corresponding to the one below it. The teeth are few, but they are enormous and totally unlike those of any other animal. Now this creature led to a great deal of debate on the part of some of our greatest naturalists. Some considered it to be an amiable animal which only ate the mangold wurtzel and turnips of the period; others, amongst whom was Professor Owen, believed it to have been

a most bloodthirsty creature, and that these teeth were given to it to champ and to crush the flesh and bones of the invalid and injured creatures whose bones have just been described. The discussion is not settled yet. What I wish to point out is that this creature, with its big head and jaws, belongs to the great kangaroo tribe, but is of an extinct kind. This great creature is called the pouched lion. Mixed up with the bones of these creatures were the bones of the ordinary kangaroo, of the kinds living at the present day; so that some of the old animals of Australia, which disappeared a long time ago, were the ancestors of those which now roam over the plains. The bones of wingless birds, resembling those now characteristic of the province more than any other, have also been found in positions denoting that they have been undisturbed for a very long time; and thus the animals and birds of old resembled those now living in a general sense, and this province has a great antiquity.

The beasts now extinct, and which were so large, must have had great powers of resistance to enemies and to climate. How is it they died out? This is a point of peculiar interest because the evidence we have to offer relates to the fact that their feeding grounds became restricted in extent, and that the climate of Australia became dry and in some parts hotter. All the central part of Australia from, north to south, is more or less bare and desert-like. It lacks moisture, and is very hot, and there are very few animals roaming over it. The eastern and western provinces, on the contrary, are fertile, and are inhabited by numerous animals at the present time, but the slopes of the hills towards the centre resemble, in the climate and drought, the desert more or less. Now all geologists are agreed that this great central desert of Australia has not long been formed. It appears that the whole of central Australia at a certain time was under the sea—that a great sea, in fact, ran up the centre of the island; then, that the whole of Australia was lifted up a certain number of feet and the sea became dry land, with this result, that instead of there being an equable and moist climate produced by the neighbouring sea, an intensely hot and dry one was caused, because the sandy ground radiated the heat and absorbed all moisture. In other words, the last great change in the surface of Australia was the formation of a great central desert which altered the climate and rainfall of the district entirely; and it was probably this climatic alteration and the destruction of the inland forests which determined the extinction of these animals.

We pass on to the third great natural history province, which is that of the whole of South America, as far north as the high tableland in Mexico. This high tableland prevents most of the animals of South America from passing into North America at the present time, and evidently did so formerly. It is a very large district; and we must consider it first of all, as I have done the others, in its present condition, and then refer to its past history. If you read any books about South America you will find that the whole of the northern part of it, including the Brazils, and far south nearly to the river La Plata, is made up of forest land; except where man has cut down the forest to till the ground and build cities, there is a gigantic virgin forest extending for thousands of square miles. That was the condition of the country when first visited by Europeans. To the south the forest land gradually ceases; trees become exceedingly scarce; and then rolling plains, or pampas, of grass and thistles follow, with scarcely a tree to be seen; and where the soil is turned up it is found to be red, with a quantity of bits of lime in it. This red soil is scores of feet thick, and extends southwards to Patagonia, the north of which is about seven hundred miles from the extremity of the continent. Going south on the eastern coast the grass gradually ceases, and there is little else than a sterile and sandy desert, with a great many salt lakes. Patagonia is the most miserable and wretched country in the world—a true country of starvation. You will thus observe that there are on this continent three great and interesting districts—tree land, plains, and desert. Now, in the tree district in the Brazils there is a wonderful assemblage of animals. First of all there are the well-known American monkeys, most of which, as you may have seen in the Zoological Gardens, can hang by their tails. They differ in their anatomy from the monkeys of Africa and Asia, and are characteristic of this province. They are found in all the great forest land of South America, and high up as the Isthmus of Panama. Associated with them are some very singular creatures called "sloths." These animals, sloths by name, are to a certain extent sloths by nature, and living specimens are generally to be seen in the Zoological Gardens in London. They are small hairy animals, with exceedingly long front limbs, and with either two or three fingers, ending in long and curved claws. They have long necks, and an extremely small head in comparison with the size of the rest of the body, and the front part of the head is, as it were, cut short. On looking into their mouths it will be noticed that they have no front teeth either in the upper or lower

jaw, but there are eye teeth and back ones also. They have a great number of ribs, and the hinder quarters are made so as to allow the creature to hang from the boughs continuously, whilst the head and arms are hanging downwards; in fact, the favourite position of these sloths is to hang on to the under part of a bough, and they generally feed while they are in this position. All the arrangements of the hind limbs and feet especially, are such as will allow of a great play of motion while hanging by the claws. The fingers, if noticed, will be found to be very curious. Instead of their having three joints, as in us, there are only two; one is stuck on to the long bone of the hand, so that the first alone is movable, and that one is stuck into a long claw; and where that claw joins the bone there is a kind of outside guard, such as is seen to a certain extent in cats, or such as you might imitate by pushing the claw through the end of a very small thimble and bringing the thimble over the finger. Now the sloth tribe are distinct from all other animals by not having any front teeth; and by having the following peculiar arrangement of the front of the face. You will find, on observing it closely, that the cheek bone which goes from the eye to the ear, and which we can feel in ourselves, is not complete in the sloth; nevertheless there is a peculiar piece which hangs down, as if to protect the side of the cheek from injury. These sloths, from their living in trees, are called arboreal sloths. Living on the ground of the same forests there are other creatures which also belong to this great family of toothless animals, and with which you are familiar by the name of armadilloes. These little creatures are covered with a kind of plate-armour in which they can roll themselves up, more or less, into balls; they burrow under the ground, where they get their food to a certain extent, and live a safe life protected by their casque of mail. Their only enemies are the monkeys; and one of the tricks of the young monkeys in the American forests is, when they find an armadillo away from home, to pull its tail unmercifully, and try to drag it about. If we examine the anatomy of the armadillo we shall find that its bones greatly resemble those of the sloth; but still there are a few differences. It is a burrowing animal, and therefore it requires great power of scratching and tearing the ground. It has generally five claws, of which the outside two are not strong, and there is the same kind of thimble arrangement of the claws as is seen in the sloth. In addition, it has an arrangement in the fore arm by which there is a great leverage produced by the muscles, so that the creature can scratch the ground

vigorously. On looking at the skull it is found that they have the cheek bone perfect. In the olden time there were huge creatures living in the Brazilian forests, which must be called sloths from the structure of their bones; or more properly they may be said to belong to the toothless animals, or those which have no front teeth. One of these was found in a very peculiar position as regards the earth, and to that I shall direct your attention towards the close of the lecture. The remains were found at first piecemeal; but as years rolled on more or less perfect skeletons have been found; and this huge creature is a representation of one which is in the Madrid Museum. It is called the megatherium, or great beast. When its skeleton was put together and carefully examined, to the surprise of everybody it combined in its skeleton some parts of the anatomy of two distinct animals of the present day—the sloth and the armadillo. But you must not imagine for a moment that it ever had any armour on its back to make it like an armadillo, or that it lived up a tree: it is only in certain parts of its anatomy that it resembled these creatures. Now let us imagine what this great animal must have been like. First you will notice the exceedingly small size of the head in respect to the body, and that the skull is cut short as it were in front. There are no front teeth, but there are back teeth, which were made up of bone and a kind of cement without enamel; and they were so arranged that as they wore out they grew upwards, so that there was no succession of teeth, but the teeth continued wearing and growing to the end of the animal's life. The lower jaw you will observe is very long, and greatly resembles the under part of the jaw of the elephant. It would appear that this megatherium had a rather long tongue, and that the scoop shape of the under jaw allowed it to come out and to be directed. Then you will observe that there is a long cheek bone, from the eye to the ear bones, that it is perfect, and that it has also the curious downward process. You will observe that in the skull there are the peculiarities of the common sloth mixed up with those of the armadillo. Then there is a long neck. Next we come to the wonderful front legs, which are much longer than those behind; and this is one of the characteristics of the family. The gigantic hands or fore feet could move, like the human hands, upwards and downwards, or, as the term is, prone and supine—back and up; this is exceedingly rare in large animals. The strength of the hands was enormous. The bones were huge and the fingers were made very much on the plan

of the sloth, but they were not so long relatively. The middle finger was the largest and it had a prodigious claw; and at the junction of the claw with the bone there was this peculiar thimble-like protection on the largest, possible scale. One of the bones of the wrist stuck out backwards in order to give a certain amount of leverage, so that it could scratch and claw hold of a tree, pull down a bough, or grub up a root from the ground; and the ability to do all this was strengthened by the great size of the hind-quarters of the animal. The haunch bones were about 2ft. 8in. wider than those of the largest elephant, enabling the creature to squat down and fix its great feet solidly on the earth, whilst it was tearing away at a tree. Like all great creatures it was a vegetable feeder. The ribs were large and very broad, and it had a prodigiously long tail. Having very large ribs, great cavity of chest, and very large and wide hips, you may imagine that this creature had tremendous strength. Being a vegetable feeder it required a large cavity to contain its stomach, for it consumed a vast quantity of food, and was made on purpose to do so.

Take another example of the same group of animals. There is a smaller creature, which is built upon the same plan as the megatherium. You will observe its small head, something like the sloth, and that the snout is shortened in front, while there are no front teeth. You observe the great claws and the arrangements of the fore legs and hind-quarters, in which it resembles the megatherium. This creature, from having peculiar shaped teeth, was called the "mill-tooth beast," or mylodon. Both of these creatures belong to the set of edentata which are called tardigrades, or slow movers. They moved slowly along the ground, pulled down thetrees, and ate their leaves. You observe, especially in the megatherium, that there is a likeness with existing creatures; that it has in its structure, contrivances which belong to different animals now living.

We now pass on to the gigantic ancient representative of the armadillo. To the eye it resembles more or less that animal, and has a huge cuirass or large plate of armour covering the whole of the body, but allowing the head to show in front, and a very gorgeous tail behind. The legs come out from beneath. On looking at this creature you will see that the front part of the jaw is cut very sharply down, and that it has no front teeth. The fore and hind limbs are supplied with large and sharp digging claws, and the heel is carried back in order to enable the creature to scratch well with a great leverage. It is, in fact, something like an

armadillo, but it differs from that animal in its peculiar grooved teeth, in wanting the length of snout, in not being able to roll itself up in a ball, and in possessing a gigantic tail.

There is one specimen in the British Museum, in which the tail is of exceeding beauty; and it is one of the anomalies of nature that the creature, if it twisted itself round ever so quickly, could never catch a sight of its tail; and, therefore, the only way of accounting for its use is by supposing that the male glyptodons exhibited their beautiful endings to the females, and that those with the best tails were chosen as the best men. From the peculiar structure of the teeth, it having side teeth but no front teeth, and the side teeth being grooved, this huge animal is called the groove-tooth creature, or glyptodon. These three animals — the megatherium, mylodon, and glyptodon—belong to kinds which are no longer living on the surface of the globe; but you may compare them more or less satisfactorily with the modern creatures which live in the same natural history province. We will now go a little further down into the country and consider the plains of red earth. In this red earth, near the banks of the rivers, some very huge bones have been found, and this is a representation of the skull. You will observe it is very long and large, and that it looks uncommonly like the under part of the skull of a rabbit. This creature had very long and bent teeth, and it is called the bent-tooth beast, or toxodon. It is more like a gnawing animal than anything else; nevertheless there are several points about it which resemble some of the gigantic animals of the Old World. It was a gnawer, or rodent, as large as a rhinoceros; and although extinct it may be compared with the largest modern rodents which live on the banks of the great rivers of the district. One of them, the capybara, lives the life of a water rat, and is a peaceful vegetable feeder, falling a prey to the wild beasts of the district. The toxodon was the representative in the olden time of the gnawers which now live on the banks of the South American rivers.

Now, if we went still further south into Patagonia we should find that there the llama is the most characteristic of all the animals; and in the soil of that district have been found the bones of extinct animals which resemble it in many respects. There was a huge creature which once roamed over the plains and deserts with an extremely long neck, which is called the long-necked animal or macrauchenia, and this greatly resembled the llama in many points; it also had a resemblance to the camel and to some of the huge animals of the rhinoceros kind, but it was a

llama in habits. Now, how about the age of these creatures? How long do they carry us back? and can we explain how these huge creatures died out?

To the north of the sterile district of Patagonia some of the bones of the megatherium were found just under the surface of the soil, apparently in the remains of an old lake. In some parts of Patagonia proper similar remains were found under a vast mass of pebbles, which forms the subsoil of the country. This gigantic mass of pebbles, when examined, will give an idea of the time which elapsed whilst these great creatures were dying off from the surface of the globe. There is a river running through northern Patagonia to the Andes, a distance of about 350 miles; and the eastern coast of the country is nearly 800 miles in length, whilst the southern end is 150 miles long. It forms a kind of triangle, which is therefore of considerable extent. Wherever any river passes from the sea inland through the country it cuts through an enormous layer of pebbles, whose depth is in some places as much as 800 feet, and in others about a hundred. If we compute it to be only 200 feet thick on the average, we may form an idea of the length of time it took to wear this prodigious mass of pebbles out of the rocks of the Andes, for they came thence. Now the bones of the megatherium have been found underneath this pebble bed as well as on the top; therefore this animal lived during the whole time during which this wear and tear was going on. We may assume that one great cause of the extinction of these huge beasts in South America was the limiting of their roaming ground and the alteration of the climate. When these pebbles were formed in the bed of the sea no great harm was done, but when they were lifted up with the rest of the continent and formed dry land they produced a desert and sterility in all the surrounding country in place of the fertility which was before caused by the moisture of the ocean. This probably is one of the causes why these huge animals gradually died out, and it is probable that to the north the lifting up of the old lake beds on which the red soil collected altered the climate also. Certainly they were not destroyed by the hand of man. The small sloths and the armadilloes and monkeys lasted to the present day, because the changes did not affect them so greatly. There was one kind of animal which died out, and it is difficult enough to explain why. When the Europeans first visited South America they did not find wild horses, but there are abundance of traces of skeletons of horses associated with these great remains, already noticed, and they were horses

differing very slightly from those now living. The horse is a very hardy animal; it can move rapidly, and get out of danger, and its extinction from a district where it now breeds in vast multitudes is very curious.

You will observe, then, that in each of these three natural history provinces the present state of things was foreshadowed in the past; that in the past there was the same kind of country, but it was larger in some instances, and more fertile and moister in others; that there were many of the present kinds of animals living in the olden time associated with kinds of creatures which have died out. It is evident that the great extinct kinds with which they were thus associated resembled them greatly, and more than other animals of other provinces, and that there were none of the strangers of other remote countries there. This resemblance of the extinct and living has a very deep meaning in nature, and had I time I should be able to explain how in still earlier days these natural history provinces did not exist, but that there were others of a greater size. From what has been explained, however, we may glean the great age of the existing state of things in geography on the globe, and learn the extraordinary fact that there were some great extinct brutes which contained in their anatomy the peculiar structures of two or three modern kinds, and that the same general shape of animal was represented in the same province for vast periods of time. This cannot be by accident, for everything in this earth goes on by law; and all this hints to us that the great extinct animals and the modern ones which still live, and the kinds which existed through all these changes in the world's history, had in the distant past a common ancestry.

CAVENDISH AND HIS DISCOVERIES.

A LECTURE Delivered in the Hulme Town Hall, Manchester, on Wednesday, November 24, 1875.

BY PROFESSOR THORPE, F.R.S.E.


HEN I had the honour to appear here on a former occasion I gave you some account of the life and labours of a famous Yorkshire philosopher, Joseph Priestley, one of the most illustrious of that remarkable band of learned men which did so much to make the reign of George the Third what Lord Brougham was wont to declare it to be—the Augustan age of modern history.

To-night I shall venture to offer you a brief notice of the character and work of another and equally illustrious member of that band—Henry Cavendish. These two men had, however, little in common beyond their zeal for science; indeed, it is scarcely possible to conceive of a stronger contrast than that which their personal histories afford. Priestley, the son of a poor cloth-dresser, was ardent, impulsive, ingenuous—fond of the strife of words, never so happy, indeed, as when, Ishmael-like, his hand was against everybody and everybody's hand was against him; a man withal "in whom the elements were kindly mixed," and of whom it might be truly said that nothing which related to man was foreign to his sympathies. Cavendish, a scion of a great house, was cold, retiring, reticent, passively selfish, a confirmed misogynist, a hater of noise and bustle; and of whom it was said that he probably uttered fewer words in the course of his four-score years than any man who ever lived so long—not even excepting the monks of La Trappe. Priestley delighted in literary composition; his pen was ever busy; he published more than a hundred works on subjects of the most extraordinary diversity, turning them off with an ease and rapidity which even the most prolific of lady novelists might envy. Cavendish, although he wrote much, printed fewer pages than Priestley did works; his morbid shyness, and his horror

of popularity, compelling him to keep back his scientific memoirs even when he had prepared them for publication.

But that you may the better frame for yourselves some conception of the manner of man Cavendish was, let me attempt to sketch for you a scene in which he might have played a part. That there is nothing opposed to truth in it you may readily determine for yourselves, if what I say to-night may so far interest you in Cavendish as to lead you to read his life as written by Dr. Wilson or by Lord Brougham. Imagine, then, you are in the London of 90 years ago: it is night, and you are standing before an old-fashioned house in what is now a very unfashionable square. It is evident from the lights in the windows and the bustle before the door that there is a dinner party or some similar meeting in the house. A couple of chairmen have deposited a portly gentleman, with a large frill, on the step, and two or three lumbering vehicles, having set down their charges, are rattling away over the rough stones into the obscurity of the dimly-lighted street. My knowledge of London 90 years ago is so vague that I must ask you to complete the picture for yourselves by throwing in any other accessories which may occur to you as giving it a strong 18th century flavour, such as a few link-boys, a solitary watchman, an oil lamp or two, and a plentiful sprinkling of puddles and mud. You are informed that the house belongs to Sir Joseph Banks, who is the President of the Royal Society of London, and that the occasion is one of his weekly conversaziones. The portly visitor, with the large frill, makes his way upstairs, to the evident embarrassment of a thin, middle-aged gentleman in an old-fashioned Court dress of faded violet and a knocker-tailed periwig, who is moving uneasily about on the landing, manifestly afraid to face the assembly. The approach of the gentleman on the stairs, however, drives him into the room. He shuffles quickly from place to place, his manner is awkward; his face betrays a nervous irritation of mind, and he appears annoyed if looked at. It is the Honourable Mr. Cavendish. Finding himself close to a group, evidently, from the appearance which their faces wear, speaking of a deeply-important matter, he draws near to listen. They are talking of a rumour of some grave disaster which has befallen my Lord Cornwallis and his troops, who it would seem have been circumvented in some unexpected manner by the machinations of that arch-rebel Washington. Mr. Cavendish is scarcely interested, and he moves aside to catch something

concerning it may be some fresh eccentricity of poor Lord George Gordon, or perhaps some account of the troubles of the unhappy Mr. Watt, the engineer, who, it is being said, is fighting tooth and nail to defend his just rights from a set of unprincipled rogues who pirate his inventions. Neither of these matters are sufficiently moving to detain him. But his manner quickly alters, for he overhears the mention of the name of Mr. Herschel. Mr. Herschel is a musician at Bath, who employs his leisure in constructing big telescopes, with one of which he has just discovered a new planet. Mr. Cavendish is greatly interested; he listens with marked attention; he is even about to put a question, and begins in a nervous hesitating manner, and in a thin shrill voice, when his eye catches that of a stranger; he is instantly silent, and retires in great haste, for he has a horror of a strange face. The portly gentleman with the large frill espies him, and comes up with a foreign gentleman, who is formally introduced to Mr. Cavendish. Mr. Cavendish is assured by the portly gentleman that his foreign friend is particularly desirous to make the acquaintance of a philosopher so profound and so universally celebrated—all of which is confirmed by the foreign gentleman, who adds that it was, indeed, his chief reason for coming to London, that he might see and converse with one of the greatest ornaments of Britain, and one of the most illustrious philosophers of that or any other age. Mr. Cavendish is speechless; he is overwhelmed with confusion, until seeing an opening in the crowd he darts through it with all possible speed, and, reaching his carriage, is driven home. His house is precisely such as you would expect from one of his habits and disposition; it is made up of laboratories and workshops, and very little is set apart for personal comfort. The principal laboratory is in what the builder intended to be the drawing-room; in an adjoining chamber is a forge; and the upper apartments are turned into an astronomical observatory. Mr. Cavendish rarely did violence to his love of solitude by asking any one to his house. If a friend chanced to dine with him he was invariably treated to a leg of mutton, and nothing else. We are told that on one occasion, three or four guests being expected, he was asked what was to be got for dinner. He replied with the customary formula, "A leg of mutton." "But," said the servant, "that will not be enough for five." "Then get two legs," was his answer. During the latter part of his life Mr. Cavendish was immensely

rich. At the time of his death he was said to be worth a million and a quarter, and was the largest holder of Bank Stock in England. But he who was thus the most wealthy of learned men, and the most learned of wealthy men,* seemed quite indifferent to his riches. There is a well-known story of Cavendish threatening to remove his money out of the hands of his bankers if, as he said, they continued to plague him about it. The portrait which I throw upon the screen will give you some idea of Mr. Cavendish's personal appearance. The history of that picture is remarkable. Cavendish, as you may suppose, could never be induced to sit for his portrait; but the artist, who was bent upon having it, managed to get near his subject unobserved, and first sketching the three-cornered hat, and then the great-coat, he patiently watched his opportunity and inserted the profile between them.

The life of such a man is, as you may well imagine, nearly devoid of incident. There is but little more of his personal history to tell, except that he was the son of Lord Charles Cavendish, that he was born at Nice in 1731, and that he died in London in 1810. He died as he had lived, voluntarily severing every tie of human sympathy. When he found himself near his end, he called his servant to his bedside and said, "Mind what I say—I am going to die. When I am dead, but not till then, go to Lord George Cavendish and tell him—Go!" The dying man wished to be left alone, and the servant, who hesitated to leave him, was ordered from the room. In half-an-hour he returned to find that his master had quietly passed into

> "That undiscovered country, from whose bourn
> No traveller returns."

There is nothing lovable in such a character; on the other hand there is nothing in it that is despicable. This passionless man, whose moral character seemed almost a blank, had a marvellously clear intelligence, and a range of mental vision second to none of his age. In extent of acquirements, and in profundity of learning, he was unsurpassed by any of his contemporaries. His published work, although of the highest order, gives a very incomplete idea of his powers. He left behind him a mass of papers which indicate that he was far in advance of the science of his time. His memoirs on heat and electricity contain the germs

* Le plus riche de tous les savans et le plus savant de tous les riches.—BIOT.

of discoveries, if not actual discoveries, which are commonly associated with the names of subsequent investigators. He was an accomplished practical astronomer and a profound mathematician. His knowledge of the calculus and the manner in which he handled it have been described as masterly.

Science is indebted to a learned Scotch professor of the last century—Dr. Black—for the discovery of certain fundamental laws of heat; and the elucidation of these laws seems to have been the subject of Cavendish's earliest inquiries. One of the problems he set himself to solve, in the course of these investigations, was whether our mercurial thermometer was an accurate and uniform measurer of temperature, to the extent of showing whether the temperature of a mixture of hot and cold water is the mean of the temperatures of the hot and cold water before mixing. Having found that such was the case, Cavendish proceeded to determine the effect of mixing dissimilar liquids at different temperatures. "One would naturally imagine," he says, "that if cold mercury, or any other substance, is added to hot water, the heat of the mixture would be the same as if an equal quantity of water of the same degree of heat had been added, or, in other words, that all bodies heat and cool each other when mixed together equally in proportion to their weights."

He then shows by experiment that such is not the case. He mixed quicksilver and water together at different temperatures, and found that if it required 1lb. of water at a known temperature to cool a certain weight of hot water through a certain number of degrees, it would require 30lb. of quicksilver to cool the same weight of hot water through the same interval of temperature. He made trials with various metals, with sulphur, glass, charcoal, and many other bodies, and he concludes "that the true explanation of these phenomena seems to be that it requires a greater quantity of heat to raise the heat of some bodies a given number of degrees by the thermometer than it does to raise other bodies the same number of degrees."

We have here the first clear enunciation of a very important fact; if Cavendish had communicated his discovery to the world when he made it, namely, in 1764, he would have had priority over those who are generally styled the discoverers of the fact of specific heat. I regret that the time will not allow me to attempt to show you the full significance of this fact, for it exerts a very great influence in nature. I wish, however, to give you a clear

conception of the fact itself, namely, that two bodies, say a piece of lead and a piece of zinc, may possess the same temperature and yet contain very different quantities of heat; and, to bring it home to you, I will try and illustrate it to you by an experiment. I am about to drop these metallic balls upon this cake of wax, which is so placed that you can see its image on the screen. One of the bullets is of lead, the other is of zinc, and both will be heated to the same temperature. But you will notice that, although, as I tell you, they both possess the same temperature, they yet contain very different amounts of heat. This will be evident to you from the different amounts they give out on cooling down to the temperature of the air. The zinc bullet you see is able to melt its way through the cake whilst the leaden bullet merely buries itself a little way in the wax. [Experiment.]

Cavendish did much to improve the mercurial thermometer. He pointed out several sources of error in the methods of making and using it. He was the first to insist on the necessity of correcting its indications when the whole of the mercury is not within the space of which the temperature is to be ascertained, and the first to draw up special directions to ensure uniformity in the mode of graduating it. He also accurately determined the temperature at which quicksilver freezes, and found it to be 39 degrees below the point at which water is ordinarily turned into ice. But it would require an entire evening to indicate the value of what Cavendish did on this subject of heat. That it occupied much of his attention is obvious from the number and character of his experiments, and the excellence of his numerical results. It is evident, too, that he thought deeply on the nature of heat. He rejected the doctrine that it was material, rather holding, as he tells us, "Sir Isaac Newton's opinion, that heat consists in the internal motions of the particles of bodies;" the theory in fact which is now, I should suppose, universally current. And it is worthy of remark that one of the greatest living expositors of this theory is the director of the finest physical laboratory in the world—a laboratory erected at Cambridge to the memory of Cavendish by his descendant, the present Duke of Devonshire.

Cavendish was a natural philosopher in the widest sense of the term, for he occupied himself in turn with every branch of physical science known in his time. But it is to his discoveries in chemistry that his fame is chiefly due; and here again we may trace the influence of Black in directing the current of his

early inquiries. Chemists, up to the middle of the last century, had no clear conception of the existence of a variety of gaseous substances perfectly distinct from another. They were inclined to believe that all the different varieties of gas they met with were merely modifications of one and the same substance. Their distinctive characters were supposed to arise from their being "tainted," or "infected with fumes, vapours, or sulphurous spirits." The publication of a celebrated essay by Black on "*Magnesia Alba*," marked an epoch in the history of chemistry by demonstrating the existence of at least one uniform body totally distinct from the air we breathe. Black showed that the difference between chalk and quicklime was due to the presence of a gas in the chalk which was not in the quicklime. Quicklime, indeed, had the property of fixing this air and of thus being converted into chalk. Black named this air, which was so capable of entering into the composition of bodies, "fixed air;" now-a-days we call it carbon dioxide, a name which denotes its composition, of which Black was ignorant. Black did very little towards investigating this gas in the free state. The first full account of its properties was given by Cavendish in 1766. Cavendish prepared the fixed air with which he experimented by dissolving marble, which is, chemically speaking, the same thing as chalk, in spirits of salt or hydrochloric acid. This vessel, the reflection of which you see on the screen, contains some chalk. If I pour over it a few drops of solution of spirits of salt, or hydrochloric acid, you will see that gas is disengaged. There you see the bubbles making their way through the liquid! Cavendish found that this gas dissolved in its own bulk of water at common temperatures, and that cold water dissolves more of it than hot water; indeed, he says, "water heated to the boiling-point is so far from absorbing the air that it parts with what it had already absorded." Lime and alkalies, especially if dissolved in water, rapidly absorb the gas, but it may be collected and preserved over quicksilver for any length of time; indeed chemists owe the idea of using quicksilver to collect and preserve certain gases which are absorbed by water to Mr. Cavendish. This long tube is filled with fixed air or carbon dioxide. You see it is fitted with a cork and stopcock. I will quickly introduce into it a solution of soda. If I shake it for a moment or two, and open the end of the tube beneath the surface of this water, you will observe that the water will be forcibly driven into the tube in the form of a

fountain, to replace the carbon dioxide which has been absorbed by the soda. [Experiment.] Although you are blessed here in Manchester with one of the best water supplies in the kingdom, you doubtless have heard of such things as "hard" waters, you may even know that some of these hard waters are made "soft" by boiling, and that this particular kind of hard water deposits a crust or "fur" in the tea-kettle and a "cake" in the steam-boiler. Now this "fur" is mainly composed of chalk, kept in solution in the water by the fixed air dissolved therein. When the water is boiled the fixed air is expelled, as Cavendish tells us, and accordingly the chalk is deposited. This explanation of the origin of the "fur" was first given by Cavendish. Possibly some of you may know that such hard waters are frequently softened on the large scale by adding lime to them. The lime combines with the fixed air (the agent, you bear in mind, which keeps the chalk in solution), and accordingly the chalk is deposited, together with that formed by the union of the fixed air with the added lime. The fact that water could be thus deprived of its dissolved chalk was pointed out by Cavendish. When the carbon dioxide is allowed gradually to escape from the solution the carbonate of lime is deposited in beautiful crystals, the shapes of which are often exceedingly curious and beautiful; indeed, there is no substance which has such a diversity of crystalline forms as this carbonate of lime. Here on the screen you have a representation of certain of these forms.

In various parts of the world, particularly in districts where limestone abounds, there are large caves, or grottoes, from the roofs of which depend long icicle-shaped masses of carbonate of lime termed *stalactites*. If you notice one of these masses you will observe that occasionally a drop of water falls from the end of it to the floor, or rather upon a similar mass of carbonate of lime on the floor, exactly underneath that which hangs from the roof. The lower mass which appears to stretch up towards the upper one is termed a *stalagmite*. Occasionally the two masses do meet one another and unite to form a continuous column. The origin of these masses—these stalactites and stalagmites—will readily occur to you: the rain-water percolating through the rock above the cave contains carbonic acid in solution, by which it dissolves the carbonate of lime in the rock. As it drips from the roof it gives up a portion of its carbonic acid to the air in the cavern, and accordingly a portion of the carbonate of lime is deposited; the

next drop runs over the mass so deposited, and by giving out another portion of dissolved carbonic acid deposits another portion of carbonate of lime on the first deposition; and so the process goes on, each portion of water from the roof running down the icicle of carbonate of lime which is formed, and continually adding to its length. But the drops fall off to the floor long before they have given up the whole of their carbonic acid, and accordingly long before they have yielded up all the lime which they held in solution. Accordingly the escape of the carbonic acid goes on from the water after it has fallen on the floor and so you get this second deposit of carbonate of lime—this stalagmite—formed underneath the stalactite.

Cavendish also shewed that fixed air was considerably heavier than common air by weighing a bladder filled first with the one gas and then with the other. The fixed air he found to be one-and-a-half times heavier than the common air, a fact which I can illustrate to you by pouring the gas out of this bottle into the glass vessel on this pair of scales. You see the glass vessel appears now to weigh more, the air within having been displaced by the heavier carbon dioxide. [Experiment.] This gas will not support combustion. If I pour it over this ignited benzine you see the flame is at once extinguished. [Experiment.]

The old chemists, who in days gone by greatly busied themselves to discover a more direct method of turning things into gold than is practised by their successors in the chemical arts, have left us some marvellous stories concerning the behaviour of a gas which seems to be evolved from certain metals when they are brought into contact with acids, such as oil of vitriol, or muriatic acid. The exact nature of this gas remained unknown until Cavendish investigated its properties. This gas, which we now call hydrogen, is highly inflammable, and Cavendish showed that, like many other inflammable bodies, it cannot burn without the assistance of common air. When mixed with rather more than double its volume of air, it explodes violently on the approach of a light. [Experiment.] Cavendish also weighed this gas by the same method which he had employed to weigh the fixed air, and he found it to be eleven times lighter than common air. Cavendish, however, under-estimated the lightness of this gas; in reality it is about fourteen and a half times lighter than air. If then we can pour the heavy fixed air downwards, we may expect to be able to pour the light hydrogen upwards. I will allow the hydrogen from

this bottle to flow into the large glass vessel, which, you see, is counterpoised on this balance. As the lighter hydrogen rises and displaces the air the vessel will appear to weigh less. [Experiment.] I may show you another experiment, which has the advantage of illustrating at once all the properties of hydrogen to which I have referred namely, its inflammability, its lightness, and the fact that it forms an explosive mixture with air. This bottomless jar is filled with hydrogen. When I apply a flame to the bent tube, the light hydrogen which is rushing up through it will ignite; but as the hydrogen makes its escape, air enters at the bottom; and this air, mixing with the remaining hydrogen, forms, as you will hear, an explosive mixture. [Explosion.]

When giving you an account of Priestley's work, I described to you his method of analysing the air. It was based on the fact that when the gas known as *nitric oxide* comes into contact with air, the oxygen in the air combines with the nitric oxide to form a product soluble in water. If the mixture of gases is made in a tube standing over water, the diminution in volume, consequent on the removal of the oxygen, is a measure of the amount of that gas in the air. As the quality of the air was supposed to depend upon the diminution of volume which it suffered by being mixed with nitric oxide, the instruments designed to make the tests, were termed *eudiometers*, from two Greek words denoting a 'measure of goodness.' Without going into details I may say that this method of analysis is liable to an objection from the cause first worked out by our illustrious townsman, John Dalton, that the same volume of oxygen can combine with different volumes of the nitric oxide. This fact was indeed known to Cavendish, and he made a great number of experiments in order to ascertain the best method of mixing the gases so as to obtain constant results.

By means of the apparatus he devised he was enabled to show that the composition of the atmosphere is sensibly constant. He tells us that "during the last half of the year 1781 I tried the air of near sixty different days * * * but found no difference that I could be sure of, though the wind and weather on those days were very various, some of them being very fair and clear, others very wet, and others very foggy." This conclusion is in harmony with the results of later experimenters. The atmosphere has practically the same composition all the world over, and all the year round. Cavendish gives us the numerical results of his experiments, and from these it appears that, when expressed in the

manner we now adopt, the mean composition of the air is in 100 parts by measure:—

O—20·8
N—79·2

The most refined methods of analysis of modern times have shown that the mean numbers are

O—20·9
N—79·1

A result, you see; almost identical with that deduced from Cavendish's observations, and one which illustrates in a very striking manner the extreme care and accuracy with which he worked.

Cavendish next proceeded to determine the cause of the diminution in volume which common air suffers by the action of burning bodies upon it.

Among the many experiments which he made in order to elucidate this matter there is one which is especially remarkable, as it led him to his greatest discovery, that of the composition of water—a discovery which will make the name of Cavendish for ever memorable. Dr. Priestley relates in one of his volumes of "Experiments and Observations on Air," that when a mixture of common air and inflammable air is exploded by the electric spark in a glass vessel, "the inside of the glass, though clear and dry before, immediately became dewy." "As this experiment," says Cavendish, "seemed likely to throw great light on the subject I had in view, I thought it well worth examining more closely." Cavendish repeated this experiment in his characteristically careful manner. The inflammable air and common air were mixed in varying but known proportions, and the diminution in volume which attended the explosion in each case was accurately noted, and the amount of oxygen remaining in the air was determined by the eudiometer. Cavendish found that the greatest diminution of volume occured when two volumes of hydrogen were mixed with five volumes of air.

He tells us that when this mixture is exploded, "almost all the inflammable air and about one-fifth part of the common air lose their elasticity, and are condensed into the dew which lines the glass." Cavendish continues: "The better to examine the nature of this dew 500,000 grain measures of inflammable air were burnt

with about two and a half times that quantity of common air, and the burnt air made to pass through a glass cylinder 8ft. long and ¾in. in diameter, in order to deposit the dew. The two airs were conveyed slowly into this cylinder by separate copper pipes, passing through a brass plate which stopped up the end of the cylinder; and as neither inflammable air nor common air can burn by themselves, there was no danger of the flame spreading into the magazines from which they were conveyed. * * * * By this means upwards of 135 grains of water were condensed in the cylinder, which had no taste nor smell, and which left no sensible sediment when evaporated to dryness; in short it seemed pure water." * * * By the experiments with the globe it appeared that when inflammable air and common air are exploded in a proper proportion, almost all the inflammable air and near one-fifth of the common air lose their elasticity, and are condensed into dew. And by this experiment it appears that this dew is plain water, and consequently that almost all the inflammable air and about one-fifth of the common air are turned into pure water."—

Cavendish then repeated the experiment with pure oxygen, or "dephlogisticated air," as this gas was then termed. I will give you the result in his own words, for the account has a great historical interest: "I took a glass globe holding 8,800 grain measures, furnished with a brass cock, and an apparatus for firing air by electricity. This globe was exhausted by an air-pump, and then filled with a mixture of inflammable and dephlogisticated air by shutting the cock, fastening a bent glass tube to its mouth, and letting up the end of it into a glass jar, inverted in water, and containing a mixture of 19,500 grain measures of dephlogisticated air, and 37,000 of inflammable; so that on opening the cock some of this mixed air rushed through the bent tube and filled the globe. The cock was then shut, and the included air fired by electricity, by which means almost all of it lost its elasticity. The cock was then again opened, so as to let in more of the same air, to supply the place of that destroyed by the explosion, which was again fired, and the operation continued till almost the whole of the mixture was let into the globe and exploded. By this means, though the globe held not more than the sixth part of the mixture, almost the whole of it was exploded in it, without any fresh exhaustion of the globe." Cavendish, however, found that in many of his trials the condensed water was sensibly acid to the taste, and by saturation with alkali, and evaporation, it yielded

nitre. The search for the cause of the formation of this acid led Cavendish to another discovery, namely, that of the composition of nitric acid, an acid which is probably familiar to you under its old name of spirits of nitre or aquafortis. He showed that the formation of this acid was not an essential part of the process of the union of the oxygen and hydrogen, but that it was due to the presence of impurities in the gases used. Whenever the amount of oxygen was larger than could combine with all the hydrogen in the mixture, a portion of that oxygen united with the nitrogen of the common air present to form this nitric acid. I may show you an experiment in illustration of the method employed by Cavendish to effect the union of the oxygen and hydrogen. This thin glass globe is filled with a mixture of two volumes of hydrogen and one volume of oxygen. I have here an arrangement by means of which I can pass an electrical spark in this mixture. Before passing the spark I will place this wire gauze cylinder over the globe to protect us from the results of the explosion. Now I pass the spark and the glass is immediately shattered by the violence of the explosion—that is by the energy of the union of the oxygen and hydrogen. [Experiment.]

Such, then, were the experiments which led to the discovery, firstly, of the compound nature of water; secondly, of the character of its constituents; and thirdly, of the proportions in which these constituents are combined together. It would be impossible to over estimate the value of this discovery: it marks one of the grandest epochs in the history of chemistry. Who could have predicted that this most familiar of all liquids was composed of two colourless invisible gases—the one the inflammable hydrogen, the lightest substance known—the other, oxygen, the life-sustaining principle in the air we breathe—nay, the element which has been styled "the chemical centre in the scheme of nature." Nevertheless, it is easy to show that such is the case. By applying that very agent which, in the hands of Cavendish, caused the two gases to combine, I am now undoing the combination. I am passing a current of electricity through the water contained in this vessel, and you notice that gases are being evolved from the two wires. [Experiment.] By a modification of the experiment which Mr. Heywood has arranged for me I can show you that more gas is being generated at the one wire than at the other; there is, in fact, twice as much of the one gas formed as of the other. The gas formed in larger quantity is hydrogen:

the other is oxygen. Water is therefore made up of one volume oxygen combined with two volumes of hydrogen.

Nearly every important discovery has to pass through two ordeals—it is first impugned as not true, and then as not new; and this grand discovery which I have ascribed to Cavendish formed no exception to this rule. Not many years ago there was a great controversy concerning the question—Who was the discoverer of the composition of water? I am not now going to rake up the matter, for it is gradually being forgotten; and I think that every chemist now allows that the claims of Cavendish have been incontestably proved. The fact is the time was ripe for this discovery. Everybody familiar with the chemical work of the latter half of the last century will admit that the labours of a dozen of Cavendish's contemporaries were tending more or less directly to the same goal, and had Cavendish proved unequal to his opportunities his grandest discovery would not have been long delayed. It has been said that the discovery of law is regulated by law, and the history of the discovery of the composition of water affords a most striking exemplification of the truth of this remark.

The time will scarcely allow me to tell you more of what Cavendish did; but, if I am not trespassing too much on your patience, I should like just to mention another great work of his, since any account of Cavendish's labours would be very incomplete without some reference to it. An ancestor of Cavendish's was one of the first to sail round the earth. Cavendish himself was one of the first to attempt to weigh it. Cavendish, in fact, undertook to determine how much heavier the earth is than a sphere of water of equal size. There, represented on the screen, is the apparatus which he employed. It consisted of a long light wooden rod suspended horizontally by a thin wire. At the ends of the rod are leaden balls about two inches in diameter, and near these could be brought the two large spherical masses of metal which you see in the figure. By the mutual attraction of the balls, big and little, the long rod was caused to move slightly. The amount of the deviation, and the force necessary to produce it, being known, together with the weights of the balls, and the distances from their centres, the attraction of a sphere of water of the same diameter as the earth upon the ball on its surface can be calculated, from which can also be calculated the relation of the earth's density to that of water. From his experiments,

Cavendish concluded that the earth is about five and a-half times heavier than water, a result which the subsequent labours of Mr. Baily, made with extraordinary care and patience, have shown to be very near the truth. It deserves to be mentioned, however, that Newton, with that marvellous insight which now-a-days seems to us nothing less than divination, had predicted that the earth would be found to be between five and six times heavier than water.

One more remark and I have done. A celebrated living French chemist, whose patriotism we admire scarcely less than his genius, has declared that "Chemistry is a French Science, its founder was Lavoisier of immortal memory." The merit of Lavoisier is undoubtedly great, and we still feel the influence which he exerted on the development of chemistry. It is accounted the chief glory of Lavoisier that he first clearly pointed out that the principles of gravitation lie at the basis of chemistry; that chemistry is in fact a science of quantitative relations. But let us take a retrospect of Cavendish's labours. He fixed the weight of the earth; he established the proportions of the constituents of the air; he occupied himself with the quantitative study of the laws of heat; and lastly, he demonstrated the nature of water and determined its volumetric composition. Earth, air, fire, and water—each and all came within the range of his observations. Now, I ask you, what is the most striking peculiarity of this work? Is it not its thoroughly quantitative character? Weighing, measuring, calculating; such, indeed, was the essential nature of Cavendish's work. If, then, the claim of anyone to be styled the founder of chemistry as a science, rests upon his recognition of the fact that it is a science of quantitative relations, may we not also, and with equal truth, say that "Chemistry is an English Science—its founder was Cavendish of immortal memory?"

THE FUNCTIONS OF THE BRAIN.

A LECTURE Delivered in the Hulme Town Hall, Manchester, on Wednesday, December 1, 1875.

BY PROFESSOR FERRIER, M.D.



PURPOSE in this lecture, or more properly discourse, to give you a brief sketch of the functions of the brain in language as untechnical as my subject will allow. I shall also endeavour to point out to you some of the more important results of recent investigations into this extremely obscure and difficult subject.

Now, I need hardly tell you that the brain is the organ of the mind, and that it is by means of our brain that we feel, and think, and will; or, speaking more generally, that it is by means of our brain that we become cognisant of the external world, and that we are enabled intelligently to adapt our actions in accordance with the conditions by which we are surrounded. These facts are matters of general knowledge; but the problem of science is to explain, if possible, the mechanism by which these various functions are carried on. This is a problem which has engaged the attention of scientific men in all ages; and it is a problem the solution of which has been furthered by the researches of each succeeding age, though we are still very far from having reached the end, notwithstanding all that has been done up to the present time.

The brain is the summit of a complex structure, or arrangement of structures, known under the name of the cerebro-spinal nerve centres. These nerve centres form the mass which is contained in the cavity of the skull and spinal column. I have here a diagram of a section through the middle line of the body, which shows the interior of the skull and spinal column, and the position which these nerve centres occupy. All that lies within the cranium or skull is known under the name of the brain or

encephalon, so called because it lies within the head or *cephale*. That which is enclosed within the spinal column is known by the name of the spinal cord. The brain and spinal cord together, therefore, form the cerebro-spinal centres. Now, in the brain itself, we have various parts which have special names, and which perform very different functions. The largest and the most important part of the brain is that known under the name of the cerebrum, or brain proper, or the large brain. In the diagram you have a representation of the appearance of the cerebrum in the human being.

It is composed, as you will see, of two distinct halves, or hemispheres, the left and the right. These two hemispheres are connected by a transverse band, which unites the two so thoroughly together that the parts of one hemisphere are united and associated in action with corresponding parts of the other hemisphere. This transverse commissure, or *corpus callosum*, as it is called, is not seen until you tear the two hemispheres asunder along the line which divides them. The surface of the brain, or the hemispheres, is thrown into an immense number of folds or convolutions, as they are termed. This arrangement of the surface of the brain is to enable a greater amount of the grey matter which is the active part of the brain, and which lies on the surface, to be enclosed in a comparatively small space. Besides the hemispheres, or cerebrum proper, there are other nervous masses which exist at the base of the brain, and are known under the name of the basal ganglia (ganglion being the term applied to a collection of nerve structures. It really means a swelling). These masses, or ganglia, as they lie at the base of the brain, are called basal ganglia. The position of these you will see in the diagram, which represents the brain of a dog laid open so as to expose these basal ganglia, the anterior pair being called the *corpora striata*, and the other pair behind them the *optic thalami*.

There is another pair of ganglia which, in the brains of some of the lower animals, attain a very large size. These ganglia have exactly the same shape in the human brain as those in the brain of the dog, and they are called by a Latin term, signifying double twin bodies, or *corpora quadrigemina*.

These occupy a position behind the optic thalami, and give origin to the optic nerves, hence in the lower animals they are called the optic lobes.

In this drawing of the brain of the frog you see that a very large part of the brain is formed by these two optic lobes, which here stand out, but which in the human brain, and also in that of the dog, are completely covered by the hemispheres.

So in the brain of the fish, to which I point. These two large ganglia are the optic lobes, in front of which two much smaller masses are seen, which are all that represent the huge cerebral hemispheres of the human brain.

The brain of the pigeon, as seen in this diagram, presents a similar arrangement of parts. Behind the optic lobes we have another important structure, called the cerebellum, or little brain, to distinguish it from the cerebrum, or large brain. The cerebellum in man is concealed and overlapped by the cerebral hemispheres, but in some of the lower animals the cerebellum stands out distinctly. I show you in the diagram the appearance of the cerebellum in the brain of the monkey, which is essentially the same as that of man. You see the peculiar way in which the surface is arranged. It is disposed in laminar folds, quite different from the convolutions of the cerebral hemispheres. A similar appearance is presented in the cerebellum of the brain of the dog, and of the cat, as seen in the diagrams which I indicate. These are the names of the parts I shall have to allude to in the course of my subsequent remarks. These various parts are all bound up so as to form a complex whole, but it would be impossible for me here to attempt to unfold their complex and intricate anatomical connections. The brain is brought into connection with the various parts of the body by means of the medulla oblongata, which is the upper part of the spinal cord, and by the spinal cord itself, through the medium of an immense number of nerves, or nerve trunks, which they give off. From the medulla oblongata and spinal cord there come off at regular intervals, in pairs, nerves which are called the cerebro-spinal nerves. These nerves, at first distinctly visible to the naked eye, proceed outwards toward the periphery of the body, and divide and sub-divide until, in their ultimate ramifications in the organs of sense and on the surface of the body, they become so extremely small as to be perceptible only by the very highest powers of the microscope. These nerve trunks are composed of an immense number of delicate fibres, which are divided into two great classes. Anatomically there is no difference between them, but functionally there is an important difference.

One set of fibres are destined to convey impressions made on the surface of the body, and on the organs of sense, to the brain; therefore they are called the *sensory* nerves, using the term generically. They are sometimes called the *afferent* nerves, signifying *carrying to.* The second great class of nerves are called the *motor* nerves, because they generally distribute themselves to the muscles; but they are also termed *efferent* nerves. It is these nerves which convey the impulses which arise in the brain to the various muscles, by which muscular and, therefore, mechanical action is performed.

These sensory and motor nerves join corresponding tracts or columns in the spinal cord, of which you see a representation in the diagram. The sensory tracts convey impressions made on the sensory nerves to the brain, while the motor tracts convey impulses from the brain to the muscles. Therefore if you divide the spinal cord in any part of its course, all the parts below are cut off from the brain. These parts become paralyzed; and the individual has therefore no control over his muscles, and the impressions made on any part of the body below the point of section are not carried to the brain, and therefore are no longer felt. This condition is sometimes seen as the result of disease, or injury of the spinal cord. When the continuity of the spinal cord is broken you have what is known as paraplegia, or paralysis of motion and sensation in the lower part of the body.

But the spinal cord, besides being the means of conveying impressions to and from the brain, also performs very important functions as an independent nerve centre. For instance, suppose a man, as the result of an accident, has had his spinal cord broken, though he would be unable to feel if you touched him, and could not voluntarily move a muscle, yet if you tickled the soles of his feet you would observe that his legs would be thrown into violent or spasmodic action, utterly independent of any volition on his part, and entirely beyond his control. These results which are produced by tickling the soles of the feet are examples of a very important class of actions, which have an important bearing on many of the phenomena which we observe in the higher nerve centres. They are known under the name of "reflex actions." This term is given to them because the impression made upon the sensory nerve travels, as it were, up to the spinal cord, and from thence is reflected back along a motor nerve, giving rise to

a muscular contraction. In the trunks of the spinal nerves the sensory and motor fibres are mixed up; but where they join the spinal cord the sensory nerves separate themselves from the motor. This is seen in the diagram to which I point. The impression made on the sensory nerve passes by the posterior root into the grey matter in the centre of the cord. Here energy is let loose, which travels out by the anterior root to the muscles, and so causes movement.

Such is the general type of reflex action, which we see exemplified more perfectly in the nervous system of the lower animals, or the invertebrate animals, as they are termed. These reflex actions, however, are not mere vague muscular contractions. When you tickle the soles of a man's foot, the result is not vague muscular contraction, but it is a definite combination of muscular contractions, apparently with some distinct end in view. The actions regulated by the spinal cord are adapted either to withdraw that part of the body from irritation or injury, or to expel the source of offence itself. The leg will either be withdrawn, if you tickle the sole of the foot, or a spasmodic extension of the leg will be produced, by which the source of irritation may be driven off. In general, we may say that the spinal reflex actions are of a protective nature. They are particularly well exemplified in the lower animals, such as the frog. When a frog is killed by decapitation, the hind legs under the influence of irritation applied to the toes, may be made to perform a series of most wonderful and adapted actions, which so much resemble those which result from consciousness and intelligence that much dispute has arisen as to whether the spinal cord is or is not a centre of consciousness and intelligence by itself. Thus if you apply a drop of vinegar to the foot, you will observe that the animal will endeavour to wipe it off or expel it; and if it cannot succeed with one leg it may even use the other for this purpose. These, however, are only instances of purely reflex action, and if they are to be termed conscious actions they are assuredly entirely different from those of mental consciousness. We can only determine the existence of consciousness from our own experience, and we can say that in the case of man these actions are performed entirely without consciousness. We argue, therefore, that the actions of the spinal cord of the lower animals, even though more complex or apparently more intelligent in their character than those of man, are in reality of exactly the same nature. It is a difference only in degree, and not in kind.

The domain of reflex action extends to the whole of the functions of the viscera or internal organs. The spinal cord, through the medium of certain other nerve structures which are called the sympathetic nerves, and which are distributed to the various viscera, regulates all the functions of secretion, the movements of the intestines, the tone of the muscles, and the contraction of the sphnieter muscles, or those which guard the outlets of the body. These various functions are essentially dependent on reflex action.

Without entering more at length into the wonderful actions performed by the spinal cord, as an independent centre, I shall now proceed a little higher, and consider the functions of that part of the spinal cord which is situated within the skull, and which is termed the medulla oblongata. The medulla oblongata, as far as the life of the body is concerned, is the most essential part of the nervous system; we may call it the centre of life.

You will understand the applicability of this term when you consider the nature of the actions which it presides over and regulates. The medulla oblongata regulates the whole of the mechanism of respiration; it also regulates the mechanism for the distribution of blood throughout the body; and it is through the medulla oblongata again by which all those actions are performed by which the ingestion and deglutition of food are accomplished. These functions may go on quite independently of consciousness or of will on our part, and indeed they go on with more precision without our will than they would do if we were to interfere with them. If the medulla oblongata alone exist life may continue. There have been cases of children born without any brain at all, having nothing beyond the medulla oblongata and spinal cord; yet these children have been known to live for a certain period, breathing regularly, and able to suck when the nipple was placed between their lips. Such anencephalous monsters, as they are termed, have even been known to utter a cry, apparently as the result of feeling. Now all these actions are simply reflex actions, breathing being a reflex action conditioned by the stimulus of deficiency of oxygen, and deglutition being a reflex action caused by the contact of substances placed in the mouth. The action of the heart is to a certain extent independent of the medulla, but it is through the medulla that its action, and the calibre of the blood vessels are capable of being modified in a reflex manner

by impressions made on the periphery of certain sensory nerves. A cry is sometimes considered as a necessary sign of feeling, but this is by no means a necessary accompaniment; essentially it is merely a sudden expiratory effort through a narrow orifice, viz., the orifice of the glottis, or upper part of the windpipe; therefore a cry may be as much a reflex action as the muscular contraction of a limb. Similar modifications of the respiratory mechanism are seen in coughing and sneezing. If any substance irritates the bronchial tubes the air in the lungs is expelled through a narrow orifice, which constitutes a cough. So with sneezing. If anything irritates the nostrils the air is suddenly expelled from the lungs through these passages so as to remove the source of irritation, just as a frog's leg is thrown into action by a drop of vinegar placed on its foot.

When the medulla oblongata is injured instantaneous death is the result, because the respiration and circulation, on which life essentially depends, are suddenly brought to a standstill. But with the medulla alone, apart from all the higher centres, life may continue if the animal is artificially supplied with the necessary food. Beyond this the animal lies helpless in whatever position it is placed, devoid of sense or motion.

As we ascend to the higher parts of the brain, we find that the functions increase in degree of complexity. I shall now proceed to the consideration of those centres which lie between the medulla oblongata and the cerebral hemispheres. We shall arrive best at a knowledge of their functions by a process of exclusion. By determining what functions an animal is still capable of after the cerebral hemispheres have been entirely removed, over and above those belonging to the medulla oblongata and spinal cord, we get those proper to the intermediate structures, viz., the cerebellum and middle brain, or mesencephale with the optic lobes. If the cerebral hemispheres are removed from certain animals, especially those which are low in the scale, you will at first sight see very little difference in the animal's behaviour or condition. If two frogs are taken, from one of which the cerebral hemispheres have been removed, and the two placed side by side, it would be difficult to say at first sight which had been operated on. The frog so treated not only continues to breathe as usual, and to react as before to cutaneous irritation of its limbs, but it maintains its erect position very well, and resists all efforts you

make to overthrow its equilibrium. If you turn it over on its back, it will not remain so, but will turn over again and regain its feet. If you place it on a board and gradually tilt the board up, the animal will not fall off, but will clamber up so as to reach a position of security. It still retains the power of co-ordinated progression. If you touch the frog's leg it will jump forward, just like a frog in which the brain is entire. Besides these powers of standing, maintaining equilibrium, and co-ordinated progression, it also retains, to a certain extent, the faculty of emotional expression, or the outward manifestation of feeling. If a frog so treated has its back gently stroked, every time you do so it utters a croak, as if in pleasure, with the regularity of a repeater. If you thrust your finger close up to its eye it will retract its head as if it saw.

If you make a sudden noise it will start. In all these respects it acts and reacts just like a frog under ordinary conditions. But beyond this the resemblance ceases. A frog is a timid animal and will hop away at your approach. Not so with a frog deprived of its hemispheres. It knows no fear and makes no efforts at escape. If it is placed on a table, and the spot on which it has been placed accurately noted, it will, unless touched or otherwise disturbed, remain there motionless and still until it dies and becomes converted into a mummy. Surrounded by food it will die of starvation. It has no appetites, no instincts, no will, no internal springs of action; and, unless acted on by some form of sensory stimulation, remains absolutely passive and inert. Similar results are observable in the case of pigeons deprived of their cerebral hemispheres. The animal is thrown into a state of profound stupor. If you do not touch it, it will remain perfectly still; if you touch it, it will move about; if thrown into the air it will fly; if you fire a pistol close to its ear it will give a sudden start; if you bring your hand close to its eye it will start back; in fact it will act in many respects exactly the same as any other pigeon. Yet it has lost all internal springs of action; it makes no movements of its own accord; it will remain still on the same spot; surrounded by food it will die of starvation; it has no will, no appetite, no desires, no instincts, and yet it reacts in a wonderful and apparently intelligent manner. So it is, though to a less extent, with some of the higher animals—such as rabbits. In proportion, however, as we ascend the animal scale, the various cerebro-spinal nerve centres become so welded together, and are so united together in action, that the removal of

the cerebral hemispheres causes such perturbation of the whole mechanism, that the individual and independent activity of the lower centres is permanently interfered with, so that experimental demonstration of their function is practically impossible. However, by a process of reasoning and analogy, and from the observation of facts of disease, we are enabled to arrive at the conclusion that similar functions are performed by the corresponding part of the brain in man. It has been a question much debated as to how all these wonderful reactions are to be accounted for. Are they indications of consciousness and of true sensation on the part of the animal? or are they of the nature simply of reflex actions? The usual doctrine is that these actions are a sign of a certain degree and kind of sensation, which may be called crude or brute sensation. But this is not true sensation, which means consciousness of impressions. The mere fact of an animal responding by a start, if you fire a pistol beside its ear, is no proof that the animal hears. Nor does the fact of its starting back if a light be flashed before its eyes imply that the animal sees. These phenomena merely signify that certain impressions made upon the sensory nerves travel up to this part of the brain, and these excite certain movements of a more complex and associated character than the movement of a single limb, but in reality not essentially different from the reflex manifestations of the spinal cord. However, on account of the difficulty of deciding, even amongst psychologists, in what true sensation really consists, we shall term these movements responsive actions: that is to say, they are actions in response to some form of external stimulus. An animal in this condition has no power of internal action; it has no voluntary power—no spontaneity. All its actions are in response to some form of stimulus applied to its sensory nerves. When this stimulus ceases the animal ceases to perform any further action. It is, as it were, a kind of machine, which is only called into play from without. Though it apparently sees, it has no sense of sight; though it apparently hears, it has no sense of hearing; though it apparently feels, it has no sense of touch and no sense of pain; all its actions, though resembling those prompted by intelligence, are in reality only the result of the inherent primary or acquired constitution of its nerve centres. We can see, therefore, that the mere outward manifestation of feeling called forth by external stimulation is no proof of consciousness. Just as a frog may be made to croak by stroking its back,

so a dog without its cerebral hemispheres may be made to bark; and, as is well known to surgeons, a human being rendered unconscious by chloroform may utter cries, as if in pain, though in reality no pain is experienced. In all these cases the outward manifestations are merely called into play in a reflex manner. When the cerebral hemispheres exist and are in full functional activity, these manifestations coincide with true feeling; but without the hemispheres there is no true consciousness.

I might enter into a fuller description of the functions of the mesencephale and cerebellum, and of the mechanism of their performance; but as I have still so much to speak of, I must go on, only I should wish to say a few words in reference to the special part taken by the cerebellum. The cerebellum is especially the organ by which the equilibrium of the body is maintained. It is through the cerebellum, therefore, that an animal is enabled to preserve its equilibrium, even when deprived of its cerebral hemispheres. When the cerebellum is destroyed, or when it is injured, the animal reels and tumbles about like an intoxicated person. In case of disease in the cerebellum in man we find exactly the same result, viz., a reeling and staggering gait, like that of a man under the influence of alcohol. The great French physiologist, Flourens, was of opinion that alcohol acts essentially upon the cerebellum. If so, we may understand not only the reeling gait but the double vision of the drunkard; for the influence of the cerebellum extends not only to the bodily movements but also to the eyeballs, which act in association with the bodily movements.

In regard to the functions ascribed to the cerebellum by phrenologists, I think they receive no support from recent investigations. The functions which the phrenologists ascribe to the cerebellum are of the nature of instincts and appetites, which are truly mental phenomena, and as such belong to the cerebrum. All the facts which have been collected by phrenologists in support of their hypothesis are, I think, susceptible of a totally different explanation.

We have seen that an animal deprived of its cerebral hemispheres loses all true consciousness, instincts, volition, and thought; we therefore come back to the original proposition with which I started, namely, that the brain was the organ of feeling, thought, and will. It remains to explain, if possible, the mechanism of these functions, and to ascertain whether the brain, as a whole, performs

these various functions, or whether there is any localisation of faculty—whether there is any part of the brain especially concerned with sensation or will, and whether we can by physiological experiment throw any light on the mechanism of thought. The generally-accepted doctrine up to a comparatively recent date has been that there is no special localisation of function in the cerebral hemispheres—that the brain as a whole performs all the functions, and that each individual part of the brain performs the same functions as the whole; so that, provided you leave a certain amount of brain in the skull, and cut away all the rest, the functions of the parts that have been lost are completely taken up and carried out by those which remain. This theory—that there is no localisation of function in the brain—has been supported by the experiments of Flourens. According to his researches, when the brain was progressively destroyed it was not one faculty that went first, and then another, but that all the mental faculties were destroyed at one sweep.

The conclusions of Fleurens has apparently received support in many wonderful facts of diseases and injuries of the brain in man. There are numerous cases on record in which, after death, large portions of the brain have been found completely destroyed by disease; and yet the individuals have manifested no symptoms indicating the existence of such serious lesion during life. We also know of cases in which the skull has been fractured and portions of the brain have been destroyed or been cut away by the surgeon, and yet the individuals have recovered, apparently nothing the worse. One of the most remarkable cases of this kind is known in medical literature as the "American crowbar case." This relates to the case of a young man who was engaged in tamping a charge of gunpowder preparatory to blasting a rock. The charge accidentally exploded, and projected the iron bar he was using clean through the anterior part of the skull, and out at the top of his head. The iron bar was three feet long and four inches in circumference, weighing about fourteen pounds. A large part of the frontal region of his brain on the left side was thus broken up and destroyed. After the shock he felt no pain, and within a few hours he was able to walk with assistance into the surgeon's house, and give a tolerable account of the whole affair. The patient ultimately recovered, and went about the United States for a period of twelve years, showing the wound in his head, and the

large iron bar which had been driven through it. This was at first regarded as a wonderful American story, but the skull of the man is still preserved in the museum of Harvard University, so that there is no doubt about the facts. The question is, whether this man really suffered any deprivation of intelligence. He evidently lost none of his special senses or voluntary powers. It is very difficult to decide the question as to loss of intellect, unless we take as signs of this his giving himself up to intemperate habits and stumping the country, instead of remaining a sensible, sober, and industrious working man. This and other cases have been adduced to show that very large portions of the brain may be destroyed without producing any effect on the intelligence; they have also been taken to indicate that there is no localisation of function in the brain. I shall endeavour to show that this is not the true explanation of the facts. The facts may be admitted, and yet be explained differently. It entirely depends on what part of the brain is injured, and whether the injury affects the corresponding parts in both hemispheres (for we have a double brain); whether there shall or shall not be affection of sensation, or volition, or higher mental powers. A curious fact is to be noted, which those who deny localisation of the brain have never been able to account for, namely, the condition of speechlessness, or aphasia, as it is termed, which results from disease in a certain part of the brain. Such persons can understand what you say perfectly well, but they cannot utter a single word. This condition is generally found to coincide with disease in this part of the brain. [The lecturer here pointed to the posterior part of the lower frontal convolution of the left hemisphere.] Numerous cases of this kind have been reported, and it has always been difficult to account for the fact that disease in this part of the brain should cause loss of speech and nothing else. Why should it do so, if there is no localisation of faculty? The loss of speech, however, is particularly associated with disease of this region in the left hemisphere of the brain, not the right. This has furnished an argument against the theory of localisation, because the opponents say that the two brains are symmetrical, and, therefore, that we cannot without absurdity suppose a faculty to be localised in one hemisphere to the exclusion of the other. The facts which I am about to mention to you serve to throw light upon this puzzling question; and I therefore pass on to indicate some of the results

of my own researches on the localisation of function in the brain. I told you that the surface of the brain was thrown into a number of folds or convolutions, separated by grooves or fissures. You see here the side view of the human brain, and beside it, for comparison, a corresponding view of the brain of a monkey. The convolutions in the human brain are much more complex than those of the monkey, but these convolutions are not irregular, but are disposed according to a certain plan and relation to each other.

I shall point out certain leading marks by which you may recognise corresponding convolutions in the brain of the monkey and man. In the brain of the monkey you see one very large fissure, which runs obliquely upwards and backwards. This fissure is called the Fissure of Sylvius. Here is the same in the human brain. You see the situation corresponds very closely. Here is another, which proceeds downwards and forwards from the upper margin of the hemisphere, called the Fissure of Rolando. Here is the same in the brain of man, and you see that the relative position corresponds in both. Now you will observe a convolution which arches over the upper end of the Fissure of Sylvius. It is called the angular gyrus or curved convolution (pli courbe), on account of its appearance. Here is the corresponding part in the brain of man. Now this part of the brain is the centre of the sense of sight. When this part of the brain is destroyed, the sense of sight is gone in the opposite eye, though all the other senses remain, and the animal can hear and smell, and taste and touch, and perform every voluntary action the same as before. The method of experimentation by which these facts have been made out is a combination of the method of stimulating the surface of the brain with localised destruction of the part. It is a remarkable fact that the brain is insusceptible to every kind of irritation excepting electricity. You may cut and cauterise the brain without exciting sensation, though it is the organ of all feeling. This we have learned from experiments and from the testimony of men who have had their brain injured, and parts of it exposed and cut away. Such persons have no more felt cutting into the substance of the brain than if the surgeon had been cutting a piece of cheese. Nothing will artificially irritate or arouse the activity of the brain excepting electricity. This was ascertained by two German physiologists whose researches have led to the discovery of a great number of new and important results. I need not

mention the details by which the facts I am about to mention to you have been ascertained, but will simply describe briefly the conclusions to which my researches have led me. As I have said, the angular gyrus is the centre of the sense of sight for the opposite side of the body. The brain has cross action. The left hemisphere governs the right side, and the right hemisphere governs the left side of the body. Therefore when we see with our right eye we see with the left side of the brain; and when we see with our left eye we see with our right side. Another curious and exceedingly important fact is that though an animal be rendered blind by the destruction of the sight convolution on one side, its blindness is only temporary. Very soon the other hemisphere can take up the function, and then vision is possible with both eyes as before. This compensatory action of the two hemispheres is a peculiar feature of the brain, and furnishes the explanation of the fact that disease of this part of the brain may exist without causing blindness to the opposite eye. Total blindness only ensues when there is disorganisation of the same part in both hemispheres. In this way we can account for many of the cases of the existence of extensive disease of the brain without marked symptoms during life. One side of the brain may be diseased, and yet, if the corresponding part of the other hemisphere remains intact, the faculty will be apparently uninjured.

I now go on to indicate the regions or convolutions concerned in the other senses.

I point to a convolution here in that part of the brain of the monkey which is called the temporo-sphenoidal lobe; and here, again, to the corresponding part in the brain of man. [The lecturer pointed to the superior temporo-sphenoidal convolution.] This I have found to be the centre of the sense of hearing. It is with that part of the brain we hear, and the conditions are the same as for the sense of sight. From the lower extremity of this lobe (you will observe it in the brain of the lower animals more distinctly) proceeds a large tract or process which is called the olfactory tract. From this arise the nerves which penetrate into the nostrils. It is well seen in those animals which have the sense of smell largely developed, as the dog and cat. It is also very large in the brain of the rabbit, which you see here. The sense of smell is much less developed in the monkey and in man, and therefore the tract is smaller, and its connection with the tip of

this temporo-sphenoidal lobe is less apparent. When, however, this part of the brain is destroyed, the sense of smell is abolished. The action in this case is not crossed, but on the same side as the lesion. In close relation to it is the part of the brain with which we taste. The senses of taste and smell are localised together at the lower part of the temporo-sphenoidal lobe. This, again, explains certain facts which have been observed in connection with disease, more particularly from injuries to the skull. It has been known, for instance, that as the result of a severe blow on the head a man has entirely lost the senses of smell and taste, all his other faculties being retained as before. I observed such a case at King's College Hospital, a short time ago. A man fell from a van in the street on the top of his head, and was rendered insensible for a time. He recovered perfectly with the exception of the loss of the senses of smell and taste, which were so entirely gone that he could not tell the difference between sugar and epsom salts, nor perceive the most disagreeable odour applied to his nostrils. Some people might say that the loss of taste resulted to a certain extent from the loss of smell. We know how closely the sense of smell enters into what we call taste, owing to the volatile particles passing upwards to the nostrils. This is well known to nurses and mothers, who hold childrens' noses when giving them nauseous medicine, because, by cutting off the conditions of smell, the sense of taste is thereby diminished. But this is not the explanation of the case I have mentioned, because, under the treatment to which I subjected the man, the sense of taste was recovered to a great extent, so that he could tell when his tea was sweet enough, and also distinguish between the flavour of mutton and beef—a considerable effort of discrimination. But the sense of smell never returned. I have no doubt that in this and similar cases the real cause of the loss of smell and taste is injury by counter-stroke to the lower part of the temporo-sphenoidal lobe, where the centres of smell and taste are localised.

I have not mentioned yet the sense of touch, which is one of our most important sources of knowledge of the external world. The sense of touch is not localised in the convolutions on the exterior surface of the brain, and this is rather a serious fact for the phrenologist, who localises all the faculties here. The sense of touch is localised in the internal or inner surface of the hemisphere. This diagram represents the inner surface of the cerebral

hemisphere; and here you see the position of a convolution which extends downwards and forwards, and is called the hippocampal convolution. This is the centre of the sense of touch, and when this part of the brain is disorganised the sense of touch is abolished, though the other senses may be retained; so that you may cut away one sense and leave all the others. These facts show that there is a distinct localisation of regions of special sense in the brain. They are quite novel, and it may be some time before they will all be accepted by scientific men; but the data, I think, are sufficient to prove my statements conclusively.

Other regions of the brain are concerned with our voluntary movements. It has often appeared a wonderful thing that the brain, as one organ, without differentitation of function, should be able to select the muscle or combination of muscles necessary to the performance of some simple act, such as raising the hand to the mouth. This difficulty disappears to a certain extent when we find that there are certain parts of the brain which are concerned especially in the performance of certain actions. Here is the part of the brain by which the monkey moves its biceps.* Here, again, is the corresponding part in the brain of man. When, therefore, we move our biceps voluntarily this is the part of the brain which is brought into action. The homology between the brain of the monkey and of man is proved by certain facts of disease, in which, in consequence of localised irritation of the surface, the same effects are caused as follow the application of the electrical stimulus. Thus occasionally the arm may be thrown into violent convulsions, or the spasmodic action may be seen in the facial muscles; and it has been found that these effects have been due to irritation by disease of those regions which correspond to parts of the brain of the monkey, from which similar movements can be caused by electricity. So, again, there are parts of the brain for the movement of the legs, &c. The various movements of the legs have their centres in this part of the brain of the monkey. Again, this convolution, which lies immediately behind the Fissure of Rolando, is the centre for the various movements of the thumb and fingers and wrist. Here is the corresponding part in the brain of man. The various movements of the facial muscles are centralised in

*The lecturer's remarks have reference to diagrams of the brain to which he directed the attention of the audience.

this part of the brain of the monkey; and here is the corresponding region in the brain of man. At the lower part of this convolution we have centres for the movements of the lips and tongue concerned in articulation. This throws considerable light upon the curious condition of loss of speech, of which I have spoken. The other movements are all unilateral, *i.e.*, on the opposite side of the body; but the movements of the mouth and tongue are bilateral. Therefore you may destroy this part of the brain on one side without causing paralysis of the mouth or tongue. With regard to the other movements—such as those of the hands and feet and facial muscles—the general result of destruction of any of these centres of movement is complete paralysis of that movement on the opposite side of the body. This has been proved in numerous instances of localised disease of the brain in this situation.

Passing to the frontal and occipital lobes of the brain we find that investigation has not yet thrown much light on what their functions really are. They may be irritated by electricity without apparent effect. It is also exceedingly difficult to ascertain what is the effect of the removal of these parts of the brain. An animal, even when these parts of the brain are disorganised, retains all its powers of sensation and voluntary motion.

We have, however, other evidences which go to show that the frontal regions of the brain (which are much larger in man than in other animals) are associated with higher intellectual functions. What is the physiological explanation of this function we are at present unable to say. So far the facts of experiment and of disease favour the views of the phrenologists, namely, that with the development of the anterior part of the brain there is a corresponding development of the higher intellectual powers; but investigation is still needed in order thoroughly to explain this fact in physiological terms. We are likewise in the dark with respect to the occipital lobes. Experiment has not yet satisfactorily cleared up what is the function of these lobes; we can only speculate and theorise. This, however, I am desirous to avoid.

I have only indicated generally what is the physiological aspect of these various centres of sensation and motion; but I have not entered to any extent into their psychological signification. This is an exceedingly obscure and difficult subject; and as I have already exceeded the time allotted me, I would here stop. As, however, you seem still inclined to listen to me, I will endeavour

to explain a little more fully one or two points on which I have touched. Generally, I may say that the centres of sensation and of motion are also the centres of a corresponding memory, and as such form the substrata of mind.

For instance, all the impressions derived from the eye are stored up, as it were, in that part of the brain with which we see; so that we have there a sight memory. So likewise in respect of the other sensory centres. Then, again, the motorcentres are the seat of a corresponding motor memory. Applying these considerations to the explanation of aphasia, we see that in uttering words we merely make certain sounds and articulations under the influence of the sense of hearing; and these articulate sounds are taken arbitrarily to indicate certain ideas. But the memory of words is only the memory of certain articulations. Therefore it is that the parts of the brain which perform the physiological functions of articulation are also the centres of the memory of that which they perform when in a state of functional activity. Therefore the memory of articulations is stored up in that part of the brain which governs articulation. Hence destruction of this region abolishes the power of articulation and also the memory of words. Disease of the centre of articulation in the left hemisphere, as I have told you, more especially causes aphasia or loss of speech. Just as we are right-handed, so we are left-brained. Some people are left-handed and right-brained. It would appear that in speech we chiefly use the left articulating centre, just as we use the right hand in prehension, and therefore the motor centres of the left hemisphere. So, when the left side of the brain is disordered, the power of making articulations, or the faculty of speech, is gone, because it depends principally on the left hemisphere. I cannot, however, now enter more at length into this subject. I am exceedingly gratified by the attention with which you have listened to this lecture.

I have had to hurry over a great many subjects which longer time would have enabled me to treat of more fully. I would fain conclude, from the attention with which you have favoured me, that you extend to physiological science some of that interest which I know you take in those sciences which lie at the foundation of the arts and manufactures of this country; and I hope that you will not go away with the idea which some people entertain—I think they are very misguided people—that the facts I have

laid before you have no practical value, because they are not at once convertible into pounds, shillings, and pence, or into immediate additions to our personal comfort. The progress of medical science is necessarily slow, and sudden revolutions are neither to be looked for nor desired. But you may rest assured of this—that every addition to our knowledge of the brain will inevitably lead to a better appreciation and more successful prevention and treatment of a large, and it is to be feared rapidly-increasing, class, of distressing diseases of the brain and nervous system, which, even to those best acquainted with them, are still involved in profound obscurity.

ON FOOD.

A LECTURE, delivered in the Hulme Town Hall, Manchester, on Wednesday, December 8, 1875.

BY PROFESSOR HENRY E. ARMSTRONG, PH.D., SEC. C.S.

THE subject I have chosen to bring before you this evening is one which would require many lectures for its proper illustration; but it seems to me so necessary that we should all understand something about that which is of so much importance to us, and which none of us can do without, that I have selected it, although I am afraid that I shall scarcely be able to render it perfect justice. What I hope to do is to give you some idea of the nature of food and the purpose it serves; or rather, as you all know that it serves to keep you alive, *how* it is of use to us.

In November, 1871, Professor Odling lectured to you on the "Food of Plants," and he explained how plants build themselves up, as it were, from a few very simple substances in the earth and the air in which they grow, these simple substances being put together in the plant to form much less simple substances, which in turn serve us as food. The materials which form our bodies and those of animals generally are precisely the same as those which form plants; but animals are quite incapable of using as food the very simple substances which are at the disposal of plants. Without plants, therefore, animal existence, as we know it, would be impossible; and it is really they which prepare our food for us. As some of you perhaps were not present at Professor Odling's lecture, and in order to refresh the memories of those who were, I shall first give a brief sketch of the way in

which plants are built up, and that will lead me to speak of the nature of the food which plants afford to animals.

When any vegetable substance is burnt the greater part of it disappears, and only a relatively small portion remains which cannot be burnt, and which we call ashes. Thus all of you doubtless have noticed that when wood is burnt it gradually disappears, leaving only a very small amount of white, or nearly white, ashes. Now chemists have found that the part which is dissipated when vegetable matters are burnt consists of a very small number of what they call "elementary substances or elements"—substances which they cannot break up in any way into two or more different kinds of substances. These elements are carbon, hydrogen, oxygen, and nitrogen. The carbon is present in by far the largest quantity; and next in importance come hydrogen and oxygen, and then nitrogen. From what source then does the plant obtain these four elements? Professor Odling proved to you—and I must refer you to his lecture for the proof—that the carbon is not derived from matters containing carbon present in the soil, but from the carbonic acid in the air surrounding us—carbonic acid being a substance which is made up of the two elements carbon and oxygen, or, expressed in chemical language, it is a *compound* of carbon and oxygen in certain definite and invariable proportions. The greater part of the hydrogen is derived from water. You all know that plants cannot grow without water, and that water is always in contact with their roots. It is a compound of the two elements hydrogen and oxygen, and we have therefore accounted for three out of the four elements of which plants chiefly consist—namely, carbon, oxygen, and hydrogen. The nitrogen is also derived, we believe, from a substance present in the atmosphere called ammonia, which contains two elements—nitrogen and hydrogen. Lastly, the matters which go to form the ashes of plants are derived from the earth in which they grow: but although the amount of these mineral matters is extremely small they are of considerable importance—indeed, they are indispensable—not only to the plants themselves, but also, as we shall see presently, to the animals which feed upon plants.

But in what way are plants built up from carbonic acid, water, and ammonia? If I represent carbonic acid by what chemists

call a symbol or formula, instead of writing the words "carbon" and "oxygen," I should simply write their initial letters, C and O, meaning, however, by these letters not merely carbon and oxygen, but certain quantities of carbon and oxygen; and in order to express the relative amounts of carbon and oxygen which carbonic acid contains I should write COO or CO_2.

And to represent water, which contains hydrogen and oxygen united together in certain definite proportions, using the letters H and O as before as meaning certain quantities of hydrogen and oxygen, I should write H twice and O once, or H_2O.

The substances of which vegetables chiefly consist contain three elements—carbon, hydrogen, and oxygen; but we find that the hydrogen is present in just sufficient quantity to form water if united with the oxygen, so that, in fact, these substances may be regarded as compounds of carbon with water, and in consequence of this chemists have called them carbo-hydrates. The symbol for the carbo-hydrates which indicates that they consist of carbon, hydrogen, and oxygen in these relative proportions is CHHO or CH_2O. It is easy, indeed, to show by an experiment, that the carbo-hydrates may, to a certain extent, be properly regarded as compounds of carbon with water. One of the best known of them is ordinary cane sugar. I have a quantity of it in this glass, and I will add some strong sulphuric acid or oil of vitriol. This substance has a great tendency to take up water, and in a very short time the white sugar becomes black, and the mass swells up enormously, owing to the liberation of the carbon; the hydrogen and oxygen combined with the carbon in the sugar having been separated by the sulphuric acid in the form of water.

If now we compare the symbol of the carbo-hydrates with the symbols of carbonic acid and water, it is evident that they contain less oxygen than the carbonic acid and the water together:

CO_2	OH_2	CH_2O
Symbol of carbonic acid.	Symbol of water.	Symbol of carbo-hydrate.

Therefore, if we suppose that the carbo-hydrates are formed in the plant from the carbonic acid and the water, then during their formation there must have been a separation of oxygen. It is easy to prove that this really occurs. You have simply to fill a glass jar with water containing carbonic acid dissolved in it—soda-water

will do very well—and then to cover the open mouth with a plate and invert it in another vessel filled with water. If you place some growing leaves in the carbonic acid water—green parsley will answer the purpose very well—and expose the vessel to the sun, you will see that gradually gas bubbles will be given off from the leaves, and that a quantity of gas will collect at the top of the vessel. If, when a sufficient quantity of gas is collected, you place a plate under the mouth of the vessel and carefully invert it, and plunge a glowing piece of wood into this gas, you will notice that it will be rekindled and burn very brightly, which will be a proof to you that the gas is oxygen.

The question may now be asked, "Under what circumstances does this separation of oxygen take place?" Well, we find that plants only possess the power of decomposing carbonic acid and of producing carbo-hydrates when they are exposed to sunlight, and therefore we are bound to assume that in some way the sunlight is necessary. Sunlight alone, however, is not sufficient, for carbonic acid and water may be exposed together for any length of time to the sun without oxygen being separated. But, as you all know, the leaves of most plants are green, and we find on examining the leaves of any plant by the microscope, whether green or not, that they contain a very considerable amount of green matter, which has been termed chlorophyll; it is this substance which, together with the sunlight, is instrumental in causing the decomposition of carbonic acid and water in plants, and the separation of oxygen, and consequently the formation of carbo-hydrates. When a young leaf of a growing plant is examined with the microscope it is seen to be built up of what are called "cells," which are more or less regularly-shaped little boxes; and each of these cells usually contains one or more rounded bodies termed chlorophyll grains, which consist in great measure of the carbo-hydrate starch and chlorophyll. If we take a plant which is in active growth, and put it in a dark place for some days, and watch with a microscope the changes going on in the cells, we notice that the chlorophyll grains gradually become smaller, and that after a time the starch disappears from them altogether. If we then expose this plant to the light we find that the chlorophyll grains regain their former appearance, and once more become

filled with starch, and they again lose their starch if the plant is placed in the dark. The conclusion therefore is forced upon us that not only is the light active in producing starch in the plant, but also that starch is one of the first products which are formed.

The influence of sunlight in assisting the decomposition of carbonic acid is explained in the following manner: You know that when carbon or charcoal is burnt in the air it unites with the oxygen of the air and forms carbonic acid. By the union of the oxygen with the carbon what is called "*energy*" is developed in the form of heat, and the charcoal glows because the heat developed by the combination of portions of the carbon with oxygen raises the temperature of the neighbouring portions to redness. But if we want to separate the carbon and oxygen from the carbonic acid, we must restore to the carbonic acid just as much energy, either in the form of heat or some other form, as was developed by the carbon and oxygen combining to produce carbonic acid.

When plants decompose carbonic acid, setting free at least a part of its oxygen, and storing up the carbon in their tissues, the only source from which they can get the necessary energy to add to the carbonic acid, since they do not contain a store of it within themselves, is the sun. I use the term energy because it is not a fact that the plant can decompose carbonic acid with the aid of heat; it must have light for this purpose. But light and heat can be converted into one another, being different forms of what is called energy; and just as in our experiments we are able to decompose carbonic acid by the aid of heat, so plants are able to decompose it by the aid of light.

With regard to the part played by chlorophyll we know very little—in fact, we do not even know at present what is the composition of chlorophyll; but I can give you some idea of the manner in which it acts by the following experiment. I have in this cylinder a blue solution, and here a colourless solution, and if I mix them you will notice, after a time, that the blue colour has disappeared. Now the substances which I have in these two bottles are of very different natures. The blue substance has a great tendency to take up hydrogen, and is, as it were, trying to pull away hydrogen from the water in which it is dissolved. On the other hand, the colourless substance which

I have added to it has a tendency to take up oxygen; it is continually trying to pull away oxygen from the water. But the tendency of this body to take away oxygen from the water is not sufficient to overcome the tendency of the oxygen and hydrogen to remain together; and in the same way the tendency of this blue substance to take away hydrogen from the water is insufficient to enable it to decompose it. Therefore, no matter how long the blue solution and the colourless liquid are kept they remain unaltered; but when I bring the two together they assist each other, the one having a tendency for the oxygen and the other for the hydrogen, and the two together are able to decompose the water. The action of the chlorophyll is probably somewhat of this kind. The carbonic acid and the water, we may suppose, have a tendency to unite and form a carbo-hydrate with the separation of oxygen; but this tendency is not sufficient, even when the power of the sunlight is added, to overcome the tendency of the oxygen to remain united with the carbon, and of the hydrogen to remain united with the oxygen; but when we add to these tendencies that of the chlorophyll, possibly to enter into combination with the oxygen, or perhaps to enter into combination with one of the substances which is produced, then the action takes place.

Although we find a considerable number of different carbo-hydrates in plants, they are all closely related to one another. For instance, such well-known substances as starch, cane-sugar, gum, and cotton wool, are all bodies belonging to the class of carbo-hydrates; and wood itself consists mainly of carbo-hydrates. By carefully treating these substances with sulphuric acid we are able to convert them all into a kind of sugar which is found in ripe grapes and other ripe fruits, and honey, and which is therefore called grape sugar, thus proving their intimate relationship. There can be no doubt also, that just as we are able to convert such substances as starch, cotton, and woody fibre into sugar, so in the plant they may be, and probably are, all produced from sugar, or a body very closely related to it.

Besides the carbo-hydrates plants contain other compounds of carbon, oxygen, and hydrogen; and one class of these—namely, those which contain more hydrogen than the carbo-hydrates, are of considerable importance: it includes all the fats and oils. But,

in addition to the compounds of these elements, plants contain another class of substances of the highest importance, which, in addition to carbon, hydrogen, and oxygen, contain the fourth element—nitrogen. These substances are known as *albumenoids*, because of their close resemblance to white of egg, which is called albumen. If we take ordinary flour and make it into paste with water, and then wash it in a gentle stream of water, a considerable quantity is washed away, and a very sticky mass remains. This mass is known as *gluten*, being a mixture of several of these albumenoid substances. It is not possible for me in this lecture to attempt to trace in any way the formation of these albumenoid bodies in the plant, but I must call your attention to their existence, because they are of the first importance to animals as food articles, as they are the materials of which muscle is constructed; and I must now turn to the consideration of food in its relation to animals generally.

When vegetable matters are eaten by animals, which we in turn consume as food, they undergo various changes; but there is no reason to believe that these changes differ from the changes which the same substances would undergo when eaten by ourselves. It is a saving of labour, to us, however to eat a partly animal diet, because we obtain the valuable constituents of vegetable substances in a far more concentrated state than if those vegetable substances were consumed by us. The vegetable portion of our food mainly consists of carbo-hydrates, since we eat large quantities of such substances as bread and potatoes, which consist chiefly of starch; it also contains a certain proportion of albumenoids, although our chief supply of these is obtained from the lean of meat, which consists almost entirely of albumenoids. The food passes at once from the mouth into the stomach, and thence slowly through the small intestine, and from the small intestine into the large intestine. During its passage the food is undergoing a great number of changes, which fit it for distribution to the various parts of the body, for in the form in which we take it it is of little service to us, the walls of the stomach and intestines being of such a nature that it is not able to pass through them. By the action of certain juices, however, which become mixed with it in its passage through the stomach and intestines, the food undergoes alterations of such a kind that it can readily enter into circulation. In the

first place, during the time the food is being masticated in the mouth, it is mixed with the "saliva," which contains a substance having the remarkable property of acting upon starch, which is perfectly insoluble in water, in such a manner that it becomes converted into soluble sugar. Then in the stomach the food meets with another secretion, the so-called "gastric juice," which is poured out from the walls of the stomach. This gastric juice has no action on the starchy matters in the food, but it has a very powerful action indeed on the albumenoid substances. Like starch the albumenoids are insoluble in water (white of egg, for example, is not taken up by water); but after these albuminous substances have been acted upon by the gastric juice in the stomach, they become soluble in water, and capable, like sugar, of passing through the walls of the stomach.

In addition to these two secretions, when the food passes into the small intestines it becomes mixed with the bile and the pancreatic juice. Bile is a substance which is secreted by that extremely important organ of the body, the liver. It appears to have no action on the starch or albumenoid matters in the food, but it exerts a very remarkable action on another of its constituents, namely, the fat. Fat and oil, like the albumenoids and starch, are not taken up by water, and if we shake up oil and water together they do not mix; although the oil is divided into small globules, after a time these all rise to the surface and the oil separates completely from the water. But if we add some bile we find that the oil does not separate, but remains suspended in the water in the form of extremely fine particles, so fine that they are capable of passing out of the stomach and afterwards reaching the other parts of the body. All the starchy matter and albuminous substances in food, however, are not rendered soluble by the action of the saliva and the gastric juice, but the walls of the small intestine itself secrete a substance known as the intestinal juice, which, together with the pancreatic juice, completes the breaking up of the food. All the starchy matters, and the albumenoid substances which have escaped the action of the saliva and the gastric juice, are thus converted, during their passage through the small intestine, into soluble substances, and only those matters pass on, and are finally excreted, which are able to resist the action of the various secretions.

The food is thus brought into a state in which it can be distributed to all parts of the body. But how is it distributed? Most of you know, I suppose, that it is by means of the blood, which is kept constantly circulating through a system of blood-vessels, which it entirely fills, by the pumping action of the heart. The blood leaves the heart by a single wide vessel, which gives off branches in various directions, and these become more and more numerous and finer and finer, so that at last they are of such extreme fineness that they are like hairs, and are therefore termed *capillaries;* these capillaries then become wider and wider, and the branches less and less numerous, and finally they are gathered up again into a single wide vessel which leads back to the heart. The *alimentary canal*, as the stomach and intestines together are termed, is surrounded by a network of capillaries; and by the action of the various secretions on the food during its passage through the alimentary canal the solid substances are, as I have explained, greatly altered, and not only become soluble in water, but capable of diffusing or passing through the walls of the canal into these capillaries.

But in addition to the liquid and solid substances which thus pass into the capillaries, and are thence conveyed to all parts of the body, the blood contains a third kind of substance, which is at least of equal importance—namely, the gas oxygen. Blood, in fact, consists of water, in which the solid substances derived from the food are dissolved, together with oxygen and various waste products, of which mention will be made later on. This oxygen the blood takes up from the air in its passage through the lungs—air, as you have doubtless learnt from Professor Roscoe, and others, consisting mainly of the gases oxygen and nitrogen. The air we breathe passes at once through the windpipe into the lungs, which may roughly be described as consisting of a great number of hollow branches united to a central hollow trunk, the windpipe, each branch terminating in a little hollow bladder or air-cell, with very thin walls. These hollow branches and air-cells are surrounded by a very close network of capillaries, so that the blood, as it passes through the capillaries, is separated from the air in the lungs only by an extremely thin membrane, through which it can easily diffuse. Very little nitrogen passes into the blood, because blood contains a sub-

stance, to which its red colour is owing, which has no attraction for nitrogen, but unites with oxygen—in such a manner, however, that it readily yields up the oxygen again.

The heart is divided into two halves by an upright partition, and each half has two chambers—an upper and a lower—which communicate directly, but the *valves* which separate them are so arranged that the blood can only pass from the upper into the lower chamber. The blood is forced from the lower chamber on the right side of the heart through the capillaries of the lungs into the upper chamber on the left side of the heart; thence it passes into the lower chamber on the left side, and is forced into the vessels, called *arteries*, which convey it to the capillaries all over the body. From these capillaries it passes into vessels, called *veins*, which convey it to the upper chamber on the right side of the heart, and from thence it passes into the lower chamber to be again forced through the lungs. During the circulation of the blood, the substances derived from food are given up to the various parts, and thus repair the waste which is always taking place, and new tissues are formed. The oxygen in the blood assists in producing a large number of chemical changes, the nature of which is not yet thoroughly understood; and the waste products of these changes are taken up by the blood and conveyed to the organs by the aid of which they are ultimately removed from the body.

Arterial blood—that which fills the arteries—has a bright scarlet colour, and, besides being saturated with oxygen, contains the materials derived from the food. Venous blood—that which fills the veins—however, has a dark purplish colour, and contains but little oxygen, but in place of it carbonic acid and other waste materials which result from the chemical changes that have taken place in the capillaries. Thus the arteries convey the supply of nourishment to the various parts, and the veins carry away the waste products, each part of the body being provided with its system of arteries and veins. The blood which is forced from the right lower chamber of the heart through the lungs has a dark purplish colour; but in the lungs the carbonic acid is discharged from the blood, and a fresh supply of oxygen taken in, and the blood regains its bright scarlet colour. It is easy to show that the air discharged from the lungs contains a great deal of carbonic

acid by sucking air into the mouth through lime-water, and then blowing out the air from the lungs through a second quantity of lime-water. The lime-water through which the air from the lungs is passed rapidly becomes turbid, whereas the other portion remains clear. [Experiment performed.]

But not only are the various parts nourished in this way—our bodies are also being kept warm; and the reason of this is, that the oxygen carried by the blood slowly burns the various parts with which it comes in contact, forming carbonic acid and water—that is to say, the oxygen enters into combination with their carbon and hydrogen, and, as the result of this combination, heat is produced, just as when the substances are burnt or "oxidised" outside the body. I can illustrate this by the following simple experiment: I have here some sugar dissolved in cold water, and here a cold watery solution of a substance (chromic acid) which very readily parts with oxygen. In this test-tube I have some ether, a substance which need be heated very little in order for it to give off vapour which readily burns when set on fire. I place the test-tube first in the one and then in the other solution, and apply a light to its mouth, but the ether does not catch fire. Now I mix the two solutions and place the test-tube in the mixture; very soon the ether boils, and when I apply a light to the mouth of the tube its vapour takes fire and burns, thus proving that the mixture is hot. I now fit a cork, through which a bent glass tube passes, to the flask in which I have mixed the solutions, and dip the end of the tube into lime-water. Gas is given off, and soon renders the lime-water milky, proving that it is carbonic acid; so that from the oxygen of the oxygen-yielding substance and the carbon of the sugar carbonic acid is produced, and, as a consequence of the union of the carbon and the oxygen, heat is developed—the sugar, in fact, is slowly burnt. I have chosen sugar for this experiment, as we all eat more or less of it, and because the starch in our food is converted into sugar in the alimentary canal, and thence passes into the circulation. Probably, the chief purpose it serves is not to form new parts, but to warm the body in the way I have pointed out; and the only difference between the experiments I have here performed and the changes undergone by the sugar in the blood is, that in the one case the sugar is burnt by the oxygen in the chromic acid, and in the other by the oxygen in the blood.

Lastly, you will recollect I said that all vegetable matters contain small quantities of substances which remain behind as ashes when they are burnt; these substances, as I have said, are of great importance to animals as well as to plants, for we know now that it is impossible for animals to live on food which does not contain these mineral matters, as they are called. One of the most important offices of the mineral matters is to form bones, which consist chiefly of phosphate of lime. Phosphate of lime is contained in all vegetable substances, and when these are consumed by animals it gradually accumulates in their bodies, and is formed into bone. It is only one of the mineral substances, however, the value of which we can quite account for; other mineral substances, such as common salt, we know are essential to us, but it is scarcely understood at present what part they play.

From the rapid sketch which I have given of the manner in which plants are formed, and the alterations which food undergoes when consumed by ourselves and by animals generally, you will be able not only to gain an idea of the nature of the changes which take place, but also to understand how important is the relation of plants to animals in the economy of nature. In fact, animals are entirely dependent upon plants for the means of living, and the reason of this I hope now to make clear to you.

When the elements hydrogen and oxygen unite to form water, or the elements carbon and oxygen to form carbonic acid, a great deal of heat is developed, and, as I have already stated, if we wish to separate the hydrogen from the oxygen in water, or the carbon from the oxygen in carbonic acid, we must add to the water or the carbonic acid just as much heat as was developed by the union of the hydrogen and oxygen, or the carbon and oxygen. In other words, a definite amount of heat is *developed* when definite amounts of the elements unite to form a definite amount of the compound; and the same amount of heat is *absorbed* when the same amount of the compound is split up into its elements by the aid of heat.

But we can also separate hydrogen and oxygen from water, for instance, by the aid of electricity; and, on the other hand, we can cause hydrogen and oxygen to unite and form water, and develop *electricity* and not *heat* in so doing. But in this case also the amount of electricity required to split up a given weight of water

into hydrogen and oxygen is precisely equal to the electricity developed in the formation of the same weight of water from hydrogen and oxygen.

Electricity and heat, then, are different forms of what we call energy, and the examples here quoted afford instances of the same ultimate effects being produced by different forms of energy. The one form of energy may easily be converted into the other form; for example, if electricity be caused to pass through a wire which does not readily allow it to pass the wire becomes heated. Again, when a metal like zinc is dissolved in an acid like sulphuric acid a definite amount of heat is developed by the dissolution of a definite amount of zinc. If, however, the same weight of zinc be dissolved in the same acid in the galvanic battery it is found that much less heat is developed, and that, instead, electricity is produced.

Not only these two forms of energy, viz., heat and electricity, are capable of taking the place of each other, as it were, and of ultimately performing the same kind of work, but other forms of energy, such as light, under suitable conditions, may do the same.

And we can also convert these different forms of energy into work capable of producing mechanical effects, such as hoisting weights; and it has been ascertained by the most careful experiments that a definite amount of mechanical work corresponds to a definite amount of heat. If, for instance, a mixture of oxygen and hydrogen is exploded in a closed vessel with a movable top, such as the cylinder of a gas engine, the piston is raised, and the motion may be communicated to machinery, and various kinds of mechanical work accomplished; but in this case much less heat is developed than when oxygen and hydrogen combine without mechanical work of any kind being done.

We are now in a better position to understand the necessity of light to plants. Their chief food is carbonic acid and water, and they appropriate the carbon and hydrogen of these bodies but reject the greater part of the oxygen they contain—that is to say, they decompose carbonic acid and water. The plant has not the power in itself, however, of decomposing these bodies, and there is not a sufficient amount of energy in the form of heat or electricity at its disposal to enable it to do so; but it does possess

machinery, so to speak, by the aid of which it is enabled to make use of that form of energy of which there is an ample store at its disposal, viz., sunlight. Animals, however, are incapable of decomposing simple bodies like carbonic acid and water, and therefore of making use of the food at the disposal of plants, because they do not possess machinery which enables them to avail themselves, for this purpose, of any of the forms of energy at their disposal, and they are consequently dependent upon plants. The energy, in the form of light, received from the sun by plants is in a great measure stored up by them; and when vegetable matters are consumed by animals a series of chemical changes take place which are the opposite of those which occur in plants—the carbon and hydrogen separated from carbonic acid and water with the aid of energy derived from the sun, and stored up in the plant, being slowly burnt or combined with the oxygen of the air; and, as the result of this oxidation of the carbon and hydrogen, energy is developed partly in the form of heat—that is to say, the body is kept warm—and partly in the form of mechanical work. Breathing, moving the limbs, and the forcing of the blood through the arteries and veins, are all cases of work being done, and therefore involve the expenditure of energy. This energy we know is derived entirely from the chemical changes brought about by the action of the oxygen of the air on the food. Indirectly therefore animals are just as much dependent as plants upon the sun for a supply of energy; and man no less than other animals, since the animal food which he consumes is derived from animals which feed upon plants.

The office of plants being to take in carbonic acid and water, to decompose them, and to liberate oxygen, which passes into the atmosphere, that of animals is to take in oxygen and burn the carbon and hydrogen in the vegetable matters which they consume as food, thus reconverting them into carbonic acid and water. The office fulfilled by plants is the direct opposite of that fulfilled by animals, since plants are continually restoring to the atmosphere the oxygen which is consumed by animals.

But plants are not so entirely different from animals that they do not themselves require oxygen. During darkness, plants, like animals, are found to take in oxygen and give out carbonic acid; and undoubtedly this also occurs when they are exposed to sun-

light, but is not noticeable, because the amount of carbonic acid decomposed by them and the amount of oxygen given out is very largely in excess of the amount of carbonic acid given out and oxygen taken in. In fact, the more closely the chemical changes which occur during animal and plant life are investigated the more convincing the evidence becomes, that in both cases the same kinds of change take place, the difference being that in the one case certain kinds of changes take place to a greater extent than in the other.

THE TIME WHICH HAS ELAPSED SINCE THE ERA OF THE CAVE MEN OF DEVONSHIRE.

PART II.

A LECTURE delivered in the Hulme Town Hall, Manchester, on Wednesday, December 15, 1875.

BY WILLIAM PENGELLY, Esq., F.R.S.

IT may perhaps be in the recollection of some now present that, as nearly as possible, two years ago I had the pleasure of delivering a lecture in this room—I was almost going to say to this audience—on the topic on which I am to address you this evening—to wit, the time which has elapsed since the era of the cave men of Devonshire. My aim in that lecture was, not to prove how many years ago the cave men lived—for that is beyond us, and perhaps ever will be—but to show that there was good reason for believing that our fathers had under-estimated the amount of time which separates the early men of Devonshire from ourselves. On that occasion I brought before you three distinct classes of evidence, and endeavoured to show that they all told the same story. Though none of them gave a mathematical demonstration of my proposition, they concurred in their testimony. The three classes of evidence were—the deposits in Kent's cavern, or the *Geological* evidence; the animals whose remains were found in the deposits, or the *Palæontological* evidence; and, thirdly, the human industrial remains that were found commingled with the bones of the animals in the same deposits, and which we have reason to believe were coeval with them, or the *Archæological* evidence. According

to the pamphlet which I had the pleasure of purchasing to-day in Mr. Heywood's shop, I closed that lecture with the following words, and I have no doubt that the statement is correct: "I leave untouched two lines of evidence; having said nothing about the *Geographical* or the *Climatological* argument. Time will not admit of that. Each of these subjects is enough for a lecture."

I have come before you to-night with the intention of endeavouring to find the thread I dropped then, and, with your assistance, to splice on a new thread to the old one. It ought not to be difficult to form this junction, for, as you know, it is possible to drop a cable in the Atlantic Ocean, to "fish" it up some considerable time after, to splice a piece to it, and to carry it to its destination. We have something of the same kind to do to-night. It is unnecessary to ask you to give me your best attention, the subject being a little difficult, for I know from experience that the best attention that it is possible to give a Manchester audience will afford to me. The aim I have to-night is precisely that of my last lecture—not, as I have said, to prove how many years ago it was that the cave men of Devonshire lived, but that we are separated from them by an amount of time very much greater than our fathers supposed. I intend to-night to confine myself entirely to what may be called the *Geographical* evidence, and may tell you at the commencment that this divides itself into two parts—first, the evidence of changes in the *local* geography; and, secondly, the evidence of changes in the geographical relation of Britain with the Continent.

I must now call your attention to the diagrams. This is a ground plan of Kent's Cavern, made on a scale of one-fifth of an inch linear, that is, one square inch for twenty-five square feet. [Plan and extent of old and new excavations described.] Since I had the pleasure of addressing you two years ago we have made further explorations, and discovered a gallery leading into a vast chamber which perhaps will never be explored. We are still at work, and we know perfectly well that the present excavation will lead us on until we connect our work with the previous work. The uppermost deposit is what we call *Black mould*, and is an accumulation covering the eastern division of the cavern, consisting mainly of vegetable matter, together with objects left behind by people who dwelt in the cavern for some time and by

occasional visitors, and makes up a layer from three to twelve inches in thickness. Here and there, masses of limestone have fallen from the roof, and are in some cases cemented together with stalagmitic matter. Below that we have a bed of stalagmite, granular in its texture, which varies from a mere film to upwards of five feet, and averages sixteen to twenty inches in thickness. Below that, in one place only, about thirty-two feet from the entrance was a *Black band* made up mainly of charcoal, where, no doubt, the early cave men had made their fires, and had more especially dwelt. Below that we had what is called *Cave earth.* Still lower down we discovered another stalagmitic layer of much greater thickness and of crystalline texture; and below that another cave earth which we call *Breccia.* These are the various deposits. I will now try to explain to you how these deposits give us some information about the geography of the district. First, then, the two cavern entrances are situated on the steep slope of a hill. The bottom of the valley immediately below is about seventy feet under those entrances and 130 feet above the sea level. Now, if there is anything that is clearly established in the minds of those who have studied the phenomena of Kent's Cavern, it is that the Cave earth (I am now speaking of the cave earth only) was washed in through the present entrances to the cavern, which, it will be remembered, are some seventy feet above the bottom of the valley. Now it is clear that this could not have been the case unless the bottom of the valley had been nearly at the level of the entrances. The hypothesis that best explains the facts is this—that at the time the cave earth was carried into the cavern it was introduced in very small instalments, or minute quantities at a time, and after some interval a further small quantity, and so on. In the intervals the cavern was inhabited by wild animals and by men, not jointly, but alternately; they were contemporaries, something like "Box and Cox," having, not joint occupation, but alternate occupation. I have never seen "Box and Cox," but I believe my notion of it is correct. Now, we are compelled to believe that the bottom of the valley was at that time a little, and but very little, below the level of the entrances, and that in times of flood—such floods as lately laid a great part of Somersetshire under water, as I saw yesterday—such floods washed over the lip, so to speak, into the cavern, and carried in small instalments of cave earth. That was repeated until the bottom of the valley had been worn so low that even a

flood never entered the cavern. After that time nothing more was carried in, and there was an uninterrupted precipitation of stalagmite. It is a mistake to suppose that stalagmite was not being precipitated during the introduction of the cave earth. We know perfectly well that it was, because we find thin films of it at all levels in that deposit; but, being interrupted by the occasional introduction of the cave earth, a continuous sheet was not formed. But when the bottom of the valley got so deep that water could never wash in, the formation of the thick and widely-extended sheet of stalagmite commenced, and was continued without interruption. Remember that, so far as we have gone, we have to ask for time sufficient to cut down the valley seventy feet deeper, after the introduction of the cave earth ceased. The cutting of the valley a little below the level which enabled the water to flow occasionally into the cavern was the cause of the cessation of the introduction of the cave earth. Now the time required to deepen the valley to the extent of 70 feet appears at first sight to measure the entire interval between the ancient cave men and ourselves. When standing on the cavern hill, and observing that it consists entirely of hard semi-crystalline limestone, and when it is found that the hill on the other side of the valley is also made up of the same hard limestone, one cannot but feel that it would take an amount of time equal to what, with our finite powers, we understand by the word "eternity" to cut down that mass of limestone to a depth of 70 feet. I feel as much as you can do that the amount of time thus demanded is appallingly great, and I rather incline to the opinion that after all there must be some way of evading that difficulty. Now let us suppose that the valley had existed long, long before the period now under consideration; let us suppose that it had been filled up with gravel, and let us suppose that the bottom of the valley, when the water occasionally washed into the cavern, and carried in the cave earth, instead of being a limestone bottom, was simply a gravel bottom; and let us suppose that the excavation I have spoken of was not a *primary* but a *secondary* excavation, in fact a *re-excavation*, a washing or scooping out of the gravel; that, I believe, will meet the case better than supposing it to have been an excavation of the entire mass of limestone which extended primarily from one side of the valley to the other.

I trust I make myself clear here. I rather incline to say, Well,

we will be generous, and not ask you to believe that all the time requisite for scooping out a valley of that depth in hard limestone is required, but that all that is needed is time enough for scooping out the gravel which had filled a valley that previously existed. You will probably ask me, Are there any reasons for believing there ever was any gravel in this valley? Yes, ladies and gentlemen, there are. In the first place, if you examine the district you will see a series of limestone terraces. There is one at Brixham, about 200 feet above the sea level, and almost as flat—to use the language of the late Dr. Robert Chambers—as would be represented by a line drawn with a ruler. At Torquay there is another such limestone terrace, 240 feet above the sea level; and at Babbacombe there is another, 280 feet above the sea level. Ever and anon, in quarrying this limestone, a fissure is discovered extending down to an unknown depth; and always in these fissures we find gravel or rounded stones that could not have been derived from the immediate district, but must have been brought from a considerable distance; and sometimes there is found sand in sufficient quantities to make it worth the attention of builders for building purposes. Now here we have probably remnants of a gravel that not only occupied the valley, but spread over the plateaux in the neighbourhood. Further, occasionally we find little depressions cut out in the rocks, little hollows, which we call "pockets," and we meet with gravel also in them. Now suppose we go a little further eastward than Torquay. Probably many of you know Dawlish Station, on the South Devon Railway. If you leave the train at Dawlish, and walk into the valley, you find that there is a large accumulation of gravel on each side of it, and also extending up the hill slopes, suggesting that the valley was formerly occupied completely by gravel, which has been partially swept out. And that is the character and history of every valley eastward of Dawlish to the confines of Dorsetshire. With the exception of these in the pockets and fissures there are no gravels occupying the valleys about Torquay; they having been completely re-excavated. These are the reasons why I incline to the opinion that the excavation was really a *re-excavation*, a secondary, not a primary excavation. I am very glad to have this reason for believing in this re-excavation; for I repeat that I am rather appalled by the amount of time I should find myself compelled to provide for if it were not for this idea of re-excavation, for I have not told you anything like half

the story yet. I want now to convince you, if I can, that the time required for the re-excavation fails to fill the entire interval between the close of the cave earth era and the present day. This is the work immediately before me. What I have said about Kent's cavern is equally true of Brixham cavern, on the opposite side of Torbay. In 1858 a cavern was discovered at Brixham, and in it were found precisely the same classes of facts as we subsequently found in Kent's cavern. [Sketch of Brixham cavern and surrounding country.] This sketch, on the scale of one inch to twenty-four feet linear, is a fair representation of the principal valley at Brixham. Where my pointer is you see an indentation; that represents a road which was made some forty years ago. On that road is the entrance of the famous Brixham cavern. Here, again, we have good evidence that when the materials corresponding to the cave earth of Kent's Hole were carried into the cavern, the bottom of the valley must have been nearly at the same level as the cavern mouth; in other words, since the close of that period that valley has been excavated, or, as I prefer to believe, re-excavated. But what is at the bottom of the valley? People still living at Brixham remember very well the time when the material now occupying that bottom was artificially lodged there to form the road of what is now the principal street of the town. What, then, was the bottom of the valley before this made ground was lodged there? It was a peaty moss extending from that valley quite to the sea, and far out into Torbay. If you were at Torquay, and were walking thence to the railway station, you would pass along a road defended by a sea wall. Outside the sea wall there is a tidal strand mainly consisting of sand. Occasionally this sand is swept off, and you have exposed to view a peaty mass answering precisely to the peat of Brixham valley, and that peaty mass consists of blue clay and vegetable matter, stumps of trees standing erect with their roots and rootlets ramifying in a horizontal direction through the clay. It is a good example of what is termed a "submerged forest," and has been known from time immemorial. It is described by Leland and other historians, who tell us that sailors and fishermen bring up portions of it with their anchors and nets. I remember that Leland says that they bring up "musons of hartes"—that is, the antlers of deer; and, indeed, specimens of this kind have been found in considerable numbers. This forest extends seawards to

a distance where there is a depth of at least 30 feet of water at the lowest fall of the tide, and it extends up into the valleys to a height of 30 or 40 feet. This so-called submerged forest consists of three parts—the first, always covered by the sea; the second, occupying the tidal strand; and the third, sub-aerial. The same forest, as already intimated, exists in the Brixham valley.

The next thing for us to inquire into is the age of that deposit in relation to that of the cave earth. In the cave earth there are remains of animals in great plenty, but those of the sheep and the goat are never found amongst them; but in the forest, whether submerged or on the tidal strand, the sheep and the goat, and their contemporaries, are met with constantly and in considerable numbers. There is, therefore, conclusive evidence that the forest is more modern than the cave earth; hence you perceive that after the valley was re-excavated there was the growth of a forest there. So that you have to add to the time required for the re-excavation of the valley that which is represented by the growth of the forest, to fill up the interval between the era of the cave men and ourselves. Nay, you have to do more; you have to add not only the time during which the forest grew, but that time during which the forest slowly and gradually and uniformly sank, for in no instance do we find the stumps of the forest trees in any but an erect position. You have to add besides that all the time that has passed away since the forest went down to the level it now occupies; in other words, since the last adjustment of the relative level of sea and land. Let me recapitulate: We have to go backward from the present day to the time when the forest had completed its subsidence. Further back than that was the time during which the subsidence was in progress. Further back than that was the time during which the forest grew. (I am not sure that I might not say further back than that was the time during which the forest soil was deposited in the valley, but I will waive that.) Further back than that was the time during which the valley was re-excavated. Further back still was the time during which water was occasionally entering the caverns and carrying in instalments of cave earth—*and even then men lived in Devon!* We have thus a series of stepping-stones by which we can get a better idea of the amount of time than we can by looking at the whole in its entirety.

Now let us try—for this is a point of the first importance in my

lecture—if we can get any idea at all of how long ago it was that the present relative level of land and sea was established—how long ago it was that the forest ceased to subside any more. I am not sure that some of you may not say (I used to have a young friend here who pulled me up if I assumed too much. If my young friend is here now, he may say): You are now assuming two things—you are assuming that the forest *has* subsided, and that the whole country has gone *down*; and that it was not a local phenomenon but widely-spread. It was widely-spread, for we find it all round the British coasts. You have only to go down to that piece of coast between the mouth of the Mersey and the Dee, and you will find it beautifully displayed there. And that forest extends not only all round the British coast but all round the coasts of Western Europe. It is a wide-spread phenomenon. I am, therefore, right in concluding that the subsidence was also wide-spread. Secondly, you will say: Is it quite certain that the water has not risen to a higher level? May not the movement have been in the *water* instead of in the *land?* I have not time to go into that question now; but it is quite immaterial to me at present, as it is sufficient for my present purpose that there has certainly been a change in the *relative* level of the two, and that is all I care for at present. I am not prepared to deny that possibly there may have been some change in the actual level of the sea; but generally speaking the movement has been in the land and not in the sea.

Next, I ought to explain clearly what I have sometimes felt that I had failed in doing,—the difference between "subsidence" and "encroachment." Those of you who have read the history of the "Wars of the Roses," will remember that the foundation of those wars was laid at a place called Ravenspurg, on the Yorkshire coast, when the Duke of Lancaster, afterwards Henry IV., landed there in defiance of his sovereign, Richard II. You also remember that during the progress of those wars Edward IV., after having fled from Warwick, the king-maker, returned to England, and he, too, landed at Ravenspurg. Ravenspurg, therefore, fills a rather important niche in English history as well as in the writings of the dramatist and novelist. Yet, where is Ravenspurg now? There is no such place—the sea washes over that which was once Ravenspurg. Why? Simply because the sea has eaten away bit by bit—and some of the bits were rather large, no doubt—the whole of that territory. That is *encroachment*,

without any change of level, or subsidence. But when I speak of a forest having the soil remaining *in situ* and undisturbed, trees with trunks projecting above that soil in an erect position, with roots and rootlets ramifying through that soil, and the whole below the sea, that is *subsidence;* there is no encroachment, properly so called, there; the soil has not been eaten away bit by bit—there it is still. You see, therefore, the distinction between encroachment and subsidence.

Now, what we want to know is what is the least amount of time that can have elapsed between us and this first of our stepping stones—the close of the subsidence. There were numerous earlier periods. I believe you will find there are four lines of evidence open to us here. First, the amount of marine deposits that have accumulated on the forest submerged. Secondly, the amplitude of the foreshore. (I will explain what I mean shortly.) Thirdly, human works. Fourthly, human history.

I have stated that the part of the forest in Torbay which is on the tidal strand is commonly covered with sand; that the sand is occasionally, and in Torbay frequently, stripped off, and the forest left bare. But there are forests that have been seen only once in about a century. One was seen a few years ago in Bigbury Bay, between Torquay and Plymouth, that had never been exposed within the recollection of any person there. It was seen and described very accurately by a clergyman, who wrote me an account of it. There were certain traditions lingering there to the effect that a forest had once grown in that neighbourhood, but so far as is known no living man had seen it. I have myself seen a forest near Dartmouth that has only been left bare three times since the present century commenced. It is difficult then, generally speaking, to say what amount of marine deposit has accumulated on these forests, for before you can say that in any locality you must know there is a covered submerged forest there. It happens, however, that there is a county called Cornwall, and in Cornwall there is a metal that has been sought during long ages called "tin," and that tin is sometimes found in what are called stream works, that is to say, the wear and tear of the atmosphere has washed down the debris of the granite and other rocks into the valleys; and so triturated is the whole that it is possible and worth while to wash away the heavier particles and leave the tin behind. That was probably the manner in which the ancient Phœnicians taught

the Cornish people to work tin. Some of those tin works have furnished valuable information on the question now before us. There is a name that we in Cornwall are rather proud of, not on account of any theological peculiarities of the owner, but on account of his manliness—I speak of the name of Colenso—not now, however, of the Bishop, but of his father. Mr. John W. Colenso was a local geologist of considerable standing, and he described some years ago the following succession of deposits in the Pentuan valley, not far from St. Austel, in Cornwall, where the spring tides rise and fall 18 feet: First, river sand and gravel, with sea sand below, making a total of 20 feet, the upper surface being 4 feet above spring-tide level. Below that, sea sand, containing the remains of trees, red deer, oxen, whales (note the whales, which are good evidence of the marine origin of the deposit), and, near the bottom, human skulls, another 20 feet. Below that, silt, with a layer of stones, bones, and wood, 12 feet. Below that, a layer of sea sand, 4 inches thick. Below that, silt, with marine bivalve shells, perfect, the valves closed and in living position, 10 feet. Below that, a vegetable band, 8 inches thick, and at the level of 48 feet below high water. Below that again, dark silt, with vegetable matter, 1 foot. Finally, below that, the tin ground, with stumps of trees, having their roots outspread, and an oyster bed fastened to the stumps, never less than 3 feet thick; and making a total of 57 feet—that is, 53 feet below the level of spring tide. You have, therefore, clear evidence that every particle of at least 54 feet was deposited after the subsidence. Now we must not be too hasty. I have never known anything gained to the cause of truth by hastily coming to conclusions on evidence too slender, perhaps, to bear those conclusions. Let us be very careful what we are about. There is at Slapton, below Dartmouth, a beach of shingle some three miles long. I have known one single tide sweep off from the whole length and breadth of that beach material to the depth of six feet. Is it not possible, then, that such may have been the case at Pentuan with material brought from another locality? Scarcely, and for this reason—there are regular divisions in the deposits, so that the entire mass is separable into perfectly distinct and dissimilar beds. Secondly, the oysters were found attached to the stumps of the trees as they were when they grew. Thirdly, and higher up, the bivalve shells have the exact position which their modern representatives would occupy when living, the

valves closed, with nothing like a pell-mell confusion of material In short, the whole accumulation bore the character of deposits gradually accumulated one after another. That makes the subsidence amount to 53 feet as a minimum. At Carnon, in Falmouth harbour, on a branch of the river Fal, precisely the same succession of facts was met with, and carefully described by my late distinguished friend Mr. Henwood, but with this difference: the submerged forest was 67 feet below spring tide high water. We have therefore good evidence that the subsidence amounted to at least 67 feet.

I think we have in that fact a proof that there was time enough, since the last adjustment of the relative level of sea and land, for the wear and tear of the atmosphere and waves to produce, through the disintegration of the rocks, those materials which formed the successive deposits, and time enough for their transportation and deposition in the valleys. Human skulls were found in the forest itself at Carnon, not merely above it, as at Pentuan. This is one of our pieces of evidence.

Now let us come to the foreshore. I do not know whether there is any lawyer present to give us the legal definition of the "foreshore," but I will tell you what I understand by it scientifically. It is all the distance between the point at which the waves break in the most violent weather at spring tide low water, and the cliffs they assail at spring tide high water. Now suppose the whole of this country to go down 67 feet; the waves would then break relatively higher up, and by cutting away the cliff would form a new foreshore, which would expand year by year; and the amplitude of this foreshore would represent the minimum of time which had elapsed since the last adjustment of the relative level of sea and land. Now some coasts recede faster than others, for three reasons. First, you know perfectly well that soft sandstone would retreat rapidly before the waves, whereas hard granite rocks, and others as hard as the nether millstone, would scarcely show a perceptible retreat. That is the difference arising from what we call the *lithology* of the rocks. Secondly, if the beds of rocks slope towards the sea the waves run up them and scarcely do any harm. But if, on the other hand, the beds of rock overhang the waves, as they frequently do, the effect of the breakers is very destructive indeed. The most astounding difference will be seen between two localities where the rocks thus

differ in their composition and arrangement. Thirdly, some coasts, as in parts of Devonshire, are much more exposed than others—for instance, the coast west of Start Point, which is exposed to the full force of the Atlantic waves; whilst, on the other hand, the cliffs of Torbay are sheltered from almost every storm. Now I will take the coast between the Start and Prawle, in South Devon, where the rocks, though very much exposed, are of the hardest kind of mica schist, and more difficult, perhaps, to break up than if made of granite; moreover, they are arranged in such a way as to make it by no means easy to break them. Still I have it on the authority of the chief of the coastguard station there that from the point where the waves break at spring tide low water in heavy weather, to the cliff which they attack at spring tide high water, is very nearly half a mile. Since, therefore, the forest subsided, since that was a completed fact, since the last adjustment of the relative level of sea and land, the waves have had time enough to cut back the foreshore, in this most unlikely locality, until it has acquired an amplitude of very little short of half a mile. This, to the mind of the geologist, represents a prodigious amount of time. And this, again, only takes us back to our first stepping-stone. I said just now that the amplitude of the foreshore represented the "minimum" amount of time. I should like to explain why I used that word. Whilst it is true that the waves are cutting back the cliff, and would thereby be increasing the amplitude of the foreshore by so much, the same waves are grinding down the ledges forming the seaward margin, and the time must come when they will at low water break further and further in; hence the foreshore can never exceed, but it may fall short of, its true breadth; and therefore what I have spoken of is the minimum amplitude.

We now come to human works. There is an inlet of the sea which we have all heard of, and perhaps some of us have seen, called the Wash, on the eastern coast of England. The Romans embanked it to keep the sea from overflowing the adjacent low lands. In modern times it has been embanked again for the same purpose, and much land has been added. I have it on the authority of an eminent engineer that the old Roman level and the modern level, as shown by the embankments, are precisely the same; hence these works show that since the time of the Roman period there has been no subsidence, no change of level, either up

or down. Therefore two thousand years take us back, certainly no further, and probably by no means so far, as to our first stepping-stone.

Now we reach human history. Anyone who has read the account which Cæsar left of Britain will see clearly enough that he stood on the same level relatively to the sea as we stand. Anyone who reads the old Saxon Chronicles—and they are as interesting as any novel—will find that the writers, in every instance, unconsciously place themselves on precisely the same level relative to the sea as we occupy. There has been no change of level since their time; the subsidence of which I have spoken took place before they wrote. There is on the coast of Northumberland—until lately it was considered a part of the county of Durham—an island called Holy Island, or Lindisfarne. Now Sir Walter Scott, in his "Marmion," gives a description of it which is very beautiful. Of course he intended it to apply to the era of Marmion, but it also applies to the present day. Sir Walter Scott did not suppose there had been, nor has there been, any change. This is his description:—

> "The tide did now its flood-mark gain,
> And girdled in the Saint's domain:
> For, with the flow and ebb, its style
> Varies from continent to isle!
> Dryshod, o'er sands, twice every day
> The pilgrims to the shrine find way;
> Twice every day the waves efface
> Of staves and sandled feet the trace."

Marmion, c. 2, *st.* ix.

So far, Sir Walter Scott. Let us now revert to the time of Bede the Venerable. Bede was born in 673, and died in 735. He lived at Jarrow, which is almost within sight of Lindisfarne. Bede was the historian of the church in that part of England, and was perfectly well acquainted with Lindisfarne. It was his home, so to speak. Bede, in his "Ecclesiastical History," Book 3, chap. iii., page 112 (Bohn's ed.), having stated that in the year 635, Oswald, King of Northumbria, had applied to the Scots to send him a bishop, and that Aidan was accordingly sent to him, goes on to say: "On the arrival of the bishop, the king appointed him his episcopal see in the Isle of Lindisfarne, as he desired. Which place, as the tide flows and ebbs twice a day, is enclosed by the

waves of the sea like an island; and again twice in the day, when the shore is left dry, becomes contiguous to the land."

There has therefore been no change of level of the sea and land from the seventh century to the present day. The subsidence I speak of had been completed before that date. Now we will turn to my native county, Cornwall. You perhaps all know that there is a thing of beauty in Cornwall called St. Michael's Mount. [The Lecturer sketched the outline of the Mount, and the causeway connecting it with the mainland.] Now that causeway is not an artificial causeway; it is the "outcrop" of the beds of rock. I have examined it carefully, and written several papers upon it. That causeway is six feet above low water level at spring tide, and 12 feet below the spring tide high water level; the rise and fall being 18 feet Therefore, at low water, St. Michael's Mount is a peninsula, excepting in violent weather, when the causeway is sometimes impassable for a few days; and at every time of high water, when there is 12 feet of water on the causeway, it is an island. Here we have a beautiful crucial test. Had the land only been six feet lower than it is, St. Michael's Mount would never have been a peninsula, but always an island. Had it been twelve feet higher it would never have been an island. Now, what is the earliest description we have of St. Michael's Mount? We have frequent accounts of it by Leland, William of Worcester, and other writers; but I will at once take you back to that old historian, Diodorus Siculus, who wrote as follows, about the ninth year before the Christian era: "They that inhabit the British promontory of Belerium [Land's End], by reason of their converse with merchants, are more civilised and courteous to strangers than the rest are. These are the people that make the tin, which, with a great deal of care and labour, they dig out of the ground; and that being rocky, the metal is mixed with some grains of earth, out of which they melt the metal, and then refine it; then they cast it into square-like pieces like a die, and carry it to a British island near at hand, called Iktis; for at low tide, all being dry between them and the island, they convey over in carts an abundance of tin in the meantime. There is one thing peculiar to those islands which lie between Britain and Europe, for at full sea they appear to be islands, but at low water for a long way they look like so many peninsulas. Hence the merchants transport the tin they buy of

the inhabitants to Gaul; and for thirty days' journey they carry it on packs on horses' backs through Gaul to the mouth of the river Rhone." Book 5, chap. xxii.

That, then, is the earliest known description of St. Michael's Mount, and you see it answers word for word to the description we should give of it now. Therefore you perceive that, at least, two thousand years have certainly passed away since the subsidence of the forest was a completed fact. As time not allowing me to dwell longer on this part of my subject. I will briefly recapitulate. At least two thousand years ago the relative level of sea and land in Britain was the same as now. Prior to that was a period during which the whole of Western Europe subsided, at least, sixty-seven feet—even supposing that trees grew at high water mark. Prior to that was the era of the growth of the forest. Prior to that was possibly—but I will not insist on this—the era of the deposition of the blue clay in which the forest grew. Prior to that was the period of the re-excavation of the valleys to a depth of from seventy to a hundred feet lower than it was when the cave earth was carried into the caverns. Prior to the commencement of this excavation men were living in Devonshire. That is, step by step, the conclusion to which I have come respecting the changes in the *local* geography since the cave men of Devonshire lived.

In my last lecture I called attention to the fact that the animals whose remains are found in the two lowest deposits of Kent's Cavern, known as the crystalline stalagmite and the breccia, were exclusively bears, and I called the era these deposits represent, the ursine or bear era. Above this the hyæna was master of the situation, and I called it the hyænine era. Above this again, that is in the black mould, there was no hyæna, but sheep and goats, and therefore I called it the ovine or sheep era. Now, with reference to the hyæna, though there are more teeth in its head behind the canine teeth than in that of the lion and other cat-like animals, nevertheless, the number of its teeth is small in comparison with the number in the head of the horse, the rhinoceros, and most of the cave mammals—yet, waiving all this, we find that the hyænas' teeth form from thirty to forty per cent. of the entire series found in the cave earth. The following is, no doubt, the explanation of this fact:—The hyænas, being cave dwellers, dwelt in the cavern, and dragged into it piecemeal, and devoured there the carcases of the animals they found dead without.

They left traces of their teeth marks on the bones they had partially devoured; and these teeth marks are matched by the marks made by the hyænas on bones in the Zoological Gardens of to-day. The hyænas broke the bones after a peculiar fashion, just as the hyænas break bones now. The hyænas even ate their own kith and kin, though they appear to have preferred venison. Now it is a strange fact that in the *ursine* deposits there has not been found any mark of the hyæna's tooth, or any other trace of its presence. That is negative evidence, I know, but it is extremely strong; and the conclusion I come to is that the hyæna was not then in Britain. But see where that takes us. It must have been possible for him to arrive subsequently. In other words, Britain, after the ursine period, was connected with the mainland, and the English Channel was dry. This is the conclusion to which the facts of Kent's Cavern have led me. And remember that man was here during the earliest of the cavern periods, that is, man was here before the last continental condition of Britain. He saw it an island as we see it; but he also saw it as we never did see it—he saw it continental, and he saw it become insular again. But you may ask have we any evidence of this change of Britain from a continental to an insular state? We have. Hear what Sir Charles Lyell says on this point. But first let me call your attention to his scheme of geological chronology. Under the name of "Recent" are included all those deposits, and the time they represent, in which all the remains of the mammals, as well as of the mollusks, are such as still live in the world. By the word "Pleistocene" is meant those next older deposits which contain remains of mollusks all identical with species living now, but relics of mammals of which at least a part, and often a very large part, are extinct. Now, during a portion of the pleistocene period, Britain was colder than it is at present—so cold that icebergs floated in our waters, and glaciers occupied the Welsh, Cumbrian, and Scotch valleys. That was what is called the "Glacial period," or more correctly, it embraces the glacial periods, for there would seem to have been intercalated intervals during which the climate was genial, but the whole comes within the pleistocene period. Do not suppose I am saying that there were never glacial periods still earlier in the world's history. You shall now hear what Sir Charles Lyell says on this point. I quote from the last edition of his "Antiquity of Man:"—

"In order to form a connected view of the most simple series

of changes in physical geography which can possibly account for the phenomena of the glacial period, the following geographical states of the British and adjoining areas may be enumerated: First, a continental period, towards the close of which the forest of Cromer flourished, when the land was at least 500 feet above its present level, perhaps much higher. . . . The remains found in the beds of this period seem to indicate a climate somewhat milder than that now prevailing in Great Britain. [This was a pre-glacial era.] Secondly, a period of submergence, by which the land north of the Thames and Bristol Channel, and that of Ireland, was generally reduced to an archipelago. This was the period of great submergence and floating ice [in British waters.] Thirdly, a second continental period, when the beds of the glacial sea [just described] with its marine shells and erratic blocks was laid dry, and when the quantity of land equalled that of the first period. . . . During this period there were glaciers in the higher mountains of Scotland and Wales, and the Welsh glaciers pushed before them and cleared out the marine drift with which some valleys had been filled during the period of submergence. Fourthly, the next and last change comprised the breaking up of the land of the British area once more into numerous islands, ending in the present geographical condition of things. There were probably many oscillations of level during the last conversion of continuous land into islands. . . . During this period a gradual amelioration of temperature took place from the cold of the glacial period to the climate of historical times."

The author speaks of the "forest of Cromer." Those who have been on the Cromer coast, in Norfolk, will know that at the base of the cliff are frequently seen remains of ancient forests. That is the forest alluded to, and it was a pre-glacial forest; those I have been speaking of in Devon and Cornwall are post-glacial. Much of the evidence which enabled Sir Charles Lyell to draw the fine sketch just quoted was furnished him by one of your own townsmen, Mr. Darbishire, who will perhaps not thank me for mentioning his name. When Sir Charles Lyell tells you that the land north of the Thames and the Bristol Channel was submerged, he gives no opinion respecting the land south of the Thames. I have reason to believe that much of that land must be included. Hence you perceive that, independently of any facts connected with Kent's Cavern, there is good reason to believe that in times

which are very near to us geologically, though historically very remote indeed, Britain has twice been connected with the mainland—twice continental. I say that the hyæna arrived here during, but not before, the last continental condition; that the breccia was deposited before the last continental condition; and that man was here then. And you will observe that unless he had the means of navigation, he must have come here in the first continental period. In other words, the Kent's Cavern man of the breccia era was either inter-glacial or he was pre-glacial. If a navigator, he may have been inter-glacial; if not a navigator, then unquestionably he came during the first continental period, and he was pre-glacial. That is my own opinion on the question.

You will ask me—are there any deposits elsewhere which certainly belong to the first continental condition of Britain in which remains of animals have been found? Yes. In the Cromer forest remains are plentiful. Another of your distinguished townsmen has furnished us with perhaps the best list of animals found in that deposit and in that period. If you wish to see the list of the mammals found in the Cromer forest, read Professor Boyd Dawkin's "Cave Hunting," in which he gives a list of 26 species of mammals which he has himself identified, including the mammoth, the cave bear (an animal found in the breccia), and a variety of others, but not the hyæna. Hence the two facts jump harmoniously—the forest bed of Cromer says the hyæna was not there, at anyrate none of its remains are found there. The Kent's Cavern Breccia says the same thing. There is therefore nothing in the forest of Cromer to invalidate the conclusion to which I have come.

Well, now, ladies and gentlemen, there is another point. You must not conclude that because bears alone were found in the breccia that therefore nothing but bears occupied Devonshire during the era of that deposit. Remember that the remains of the mammoth are in the cavern, because the hyæna dragged them there. The remains of the horse are in the cavern, not because the horse lived there, but because the hyænas dragged it there piecemeal. So of the deer and other animals. The bear and hyæna were cave-dwellers; the other animals were not cave-dwellers; and if the hyæna had not dwelt there, though the country swarmed with the other animals, still they would not have got there.

And now I have just to say further, that those men belonging to this early period of which I have spoken were ruder men, judging from their industrial remains, than were the men of the cave earth period. I have here a case containing samples of the flint tools from the two deposits, and which I believe I exhibited two years ago. The first are the flints from the cave earth. They have a beautiful bilateral symmetry; they are made out of flakes struck off from nodules for the purpose of being made into tools, and are pretty carefully worked, but they are never polished. Those from the breccia are made out of nodules, not flakes; they have no bilateral symmetry; they are rude and massive.

So far as we know, then, the oldest men that we have sighted in Devonshire were ruder than the men of the cave earth. The men of the cave earth fashioned bone into tools. They made bone needles with eyes in them; they fashioned bones into harpoons or fish spears; we have found them in Kent's Cavern. They were fond of ornament, for they drilled holes in the fangs of badgers' canines for the purpose probably of stringing them together to wear them as necklaces, armlets, and anklets. They also made fires. But in the breccia we have no evidence of fire—nothing, in short, but these rude, massive, unsymmetrical tools.

Now I have done, with this one remark, namely, that we have been dealing all the time with *the antiquity of man in England,* not *the antiquity of man*, unless the first man appeared in England, which, considering what our climate is, cannot be very likely. The ancestors of those earliest Devonshire men, who had their advent in the world somewhere else, must be sought in still more remote antiquity.

I believe I have redeemed the pledge which I gave you at the commencement—that the lecture would be a little difficult to follow; and I am quite sure you have redeemed the pledge which you tacitly gave me, for you have been extremely and uniformly attentive to the said lecture. I can now only do what Englishmen are wont to do at this season—wish you a very Merry Christmas and a Happy New Year.

WHAT THE EARTH IS COMPOSED OF.

THREE LECTURES

BY PROFESSOR ROSCOE, F.R.S.

LECTURE I.

THE question as to the composition of the terrestrial matter, or what the earth is composed of, is one which has interested men from very early times; but it is also one the solution of which has only been even partially found within a comparatively recent period. The ideas of the ancients on this subject were vague and unsatisfactory; and it is difficult for us at the present day, when our knowledge, so far as it goes, is clear and precise, to put ourselves in the position of those who lived in past ages, or clearly to see the difficulties which those great minds had to encounter who broke through the thraldom of the Aristotelian philosophy, and prepared the way for truer views of the constitution of the earth upon which we live. From remote years, throughout the dark ages, and even down to recent times, the prestige of Aristotle altogether prevented the establishment of anything like a true view of the great phenomena of Nature. The doctrine of the existence of the four elemental states of matter—fire, air, water, earth—was generally accepted; and the possibility, nay, the proved fact, of the conversion of one kind of substance into another kind, and especially the "transmutation,"

as it was termed, of the metals, was universally acknowledged; so that the strivings of the alchemists to obtain the "philosopher's stone"—which should enable them to convert the base into the noble metals—followed as a matter of course. Next came the assumption of the existence of three principles, of which the material universe was alleged to be composed, namely, mercury, salt, and spirit, which, "mingle as mingle may," were thought, somehow or other, to produce all the different forms of matter which we see around us.

The man who, more than any other, stands conspicuous as having first distinctly opposed the prevailing views respecting the essential constitution of matter, and to whom we are indebted for the overthrow of the Aristotelian as well as the Paracelsian philosophy, is the Hon. Robert Boyle, who was born in 1627 and died in 1691. Robert Boyle was a very extraordinary man. He left behind him an extensive series of works, in which we find not only the description of a large number of important physical experiments and discoveries, but treatises upon almost every other branch of inquiry, including even theology. In his curious and interesting chapter entitled *The Sceptical Chemist*, published in 1661, he upholds the view that it is not possible, as had hitherto been supposed, to state at once the exact number of the principles or essential constituents of matter; but that, on the contrary, all those forms of matter which were not themselves capable of further separation must be regarded as simple or elementary bodies. Thus, in his introduction to the *Sceptical Chemist; or, Critical Chemico-Physical Doubts and Paradoxes touching the Experiment, whereby Vulgar Chemists are wont to endeavour to evince their Salt, Sulphur, and Mercury to be the true Principles of Things*, he uses the following expression:—

"It may as yet be doubted whether or no there be any determined number of elements; or, if you please, whether or no all compound bodies do consist of the same number of elementary ingredients or material principles."

Boyle was the first to point out the great fact—which is now the corner-stone of our science of chemistry—that a grand distinction must be drawn between compound and elementary bodies. He held, as indeed all chemists do at the present day, that chemical combination consists of an approximation of the smallest particles of matter, and that decomposition takes place when a third body is present capable of exerting on the particles of the one element a greater attraction than is possessed by the particles of the other element with which it is combined. We

have in the works of Robert Boyle, then, the first instance of the recognition of the important fact in the world of science, that there is an essential distinction between substances which the chemist is able to split up into different bodies, and those substances which the chemist is unable to divide thus; and to this latter class is given the name of *chemical elements.* I will endeavour to elucidate this difference in the essential properties of matter by an historical illustration. The year before last Professor Thorpe gave us a lecture in this hall upon the life and labours of Joseph Priestley. Those who were present on that occasion will remember that Professor Thorpe pointed out how Priestley discovered oxygen on the 1st August, 1774. They will remember that Priestley took some of this red powder, which he termed calx of mercury, and found that when it was heated by the rays of the sun it underwent a peculiar change. We cannot heat the powder at this moment by the direct rays of the sun, but we will do so by indirect solar rays, for the heat of this gas-lamp is in fact nothing but solar heat derived by a roundabout process. If I heat this red powder, as Priestley did, we find that it disappears, and that whilst the red particles disappear, certain bright globules become visible on the side of the tube; and these globules prove to be shining metallic liquid, mercury, or quicksilver. Moreover, a gas is given off which has the power of re-igniting this bit of red-hot chip of wood, as you may see, when I plunge the red-hot wood into the colourless gas contained in the tube. Here then we have a very distinct and remarkable change taking place, a change which no one could foresee, and which was not observed until about the year 1774, when Priestley made the experiment you have seen, bringing about a creation of two distinct things out of this red powder, namely, the bright metallic liquid mercury which you see here; and the colourless oxygen which we have in this globe.

The news of this discovery of Priestley's was at once conveyed to Paris, and became known to the French chemist, Lavoisier, and he then made an experiment which is of great historical interest, as not only illustrating the point upon which we are engaged, but at the same time proving the fact that the air is not a simple or elementary substance, but contains two different gases, viz., oxygen and nitrogen. For this purpose he introduced into this globular retort (Fig. 1.), the long neck of which was bent down as you see, about four ounces of pure mercury or quicksilver, and he measured carefully the exact volume of air

contained in the retort and in the bell-jar, the side of which was marked with a graduated scale. By means of a furnace he heated the mercury nearly to its boiling point. The total volume of air before he began his experiment, was exactly fifty cubic inches, at a temperature of ten degrees, and the barometer at twenty-eight inches. At first no apparent change was brought about by the action of the heat, but after a while, little red specks began to appear upon the surface of the mercury, and these specks grew larger and more numerous as the heat continued. At last, after heating it for twelve days and twelve nights, no further increase in the number and size of these

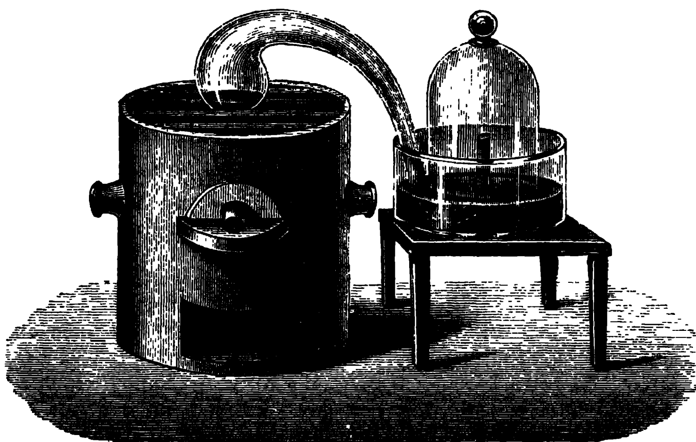
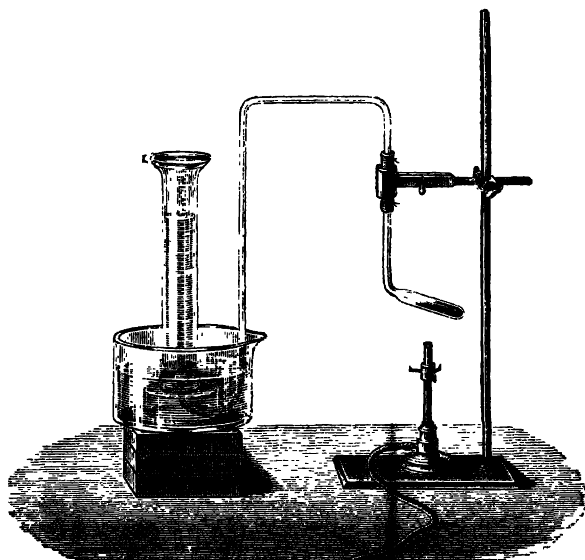


Fig. 1.

red specks was observed, and so Lavoisier allowed the whole apparatus to cool down again to ten degrees. He then once more measured the volume of air, and he found that instead of having fifty cubic inches of residual air, the volume was reduced to between forty-two and forty-three cubic inches; so that it appeared that from seven to eight cubic inches of air had disappeared. Lavoisier next took his apparatus to pieces, and collected carefully all the red powder, which he found to weigh exactly forty-five grains. The next part of his experiment is illustrated. He took the forty-five grains and placed them in the small tube-retort (Fig. 2), and proceeded to heat the powder by means of a lamp, having a gas delivery tube so arranged that

he could collect and measure any gas which might be given off in a graduated cylinder. After he had heated these forty-five grains of powder for some time, he found that a gas made its appearance, whilst at the same time mercury was deposited on the sides of the tube. When the operation was completed, and the whole of the powder had undergone this change, Lavoisier observed that between seven and eight cubic inches of a peculiar gas had come over into his cylinder, and this gas had the property of re-igniting a red-hot splinter of wood: it was, in fact, oxygen gas, or "vital air" as it was then termed, which Priestley had previously discovered.



I will now give you another illustration of the possibility of splitting up some kinds of matter into different constituents. In the year 1783, some time, as you will observe, after the discovery of oxygen gas, a man of whom you have also heard, and whose discoveries were pointed out to you last year by Dr. Thorpe, I mean the great Henry Cavendish, proved that water is not an elementary substance, but that it may be produced by bringing

together two quite different kinds of matter, that is, these two colourless gases, which we term oxygen and hydrogen. Cavendish showed that when these two gases, the first of which was then termed dephlogisticated air, and the latter inflammable air, were united in the right proportion, namely, one volume of oxygen and two volumes of hydrogen, they produced water, and nothing besides. In the year 1800, some seventeen years after this discovery by Cavendish, the action of electricity upon water was discovered by Nicholson and Carlisle; and it was found that by sending a current of electricity through acidulated water, we can actually separate the constituent parts of water, and obtain an evolution of the two permanent

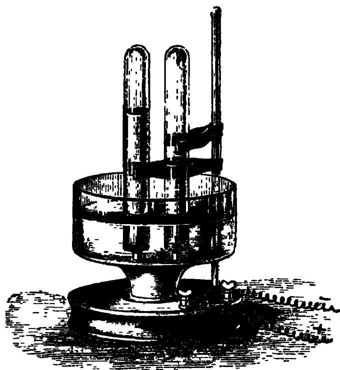


FIG. 3.

gases. In order to illustrate this fact, I will pass a current of electricity through some acidulated water, and the moment I make the contact of the wires, you see on the screen a rapid ebullition of the water, but in which the bubbles do not consist of steam, but of permanent oxygen and hydrogen gases. From this we learn that water is composed of these two gases. Next I have to show you how we can ascertain the exact quantity of the two gases necessary to be combined to form water. Instead of allowing the bubbles to escape, as in the previous experiment, I will collect from the one wire the oxygen, and from the other the hydrogen, gas. You see now that bubbles are rising from both wires, and you will notice in a short time that the two gases will collect in their separate tubes; you will likewise observe

(Fig. 3) that the volume of gas in one tube is larger than the other; and when we make the experiment with care, we find that the volume in the one case is exactly double that in the other, the oxygen being always exactly half the volume of the hydrogen. Here then we have another instance that such an apparently simple substance as water can be split up into two totally different substances—oxygen and hydrogen.

As a third instance of the decomposition of substances into two or more essentially different bodies, I may take this white salt, called sugar of lead, and I show you that it contains the well-known metal lead. This metal I can obtain from the white powder by a similar kind of process to that which I adopted for the extraction of the mercury from Priestley's red calx, only that in place of heat I shall employ electricity for the purpose of separating out the lead. You now see that when we make the contact we obtain on the screen a beautiful crystallization of metallic lead. You observe that the crystals are beginning to grow, and are throwing out their arborescent shoots over the screen. From the other wire we have the evolution of bubbles which if collected would turn out to consist of oxygen gas. In the time of Lavoisier, only seventeen elementary substances were known, and these seventeen bodies were the bricks out of which the chemistry of that time had to be built. These seventeen elementary bodies were divided into three classes: we have:—

ELEMENTS KNOWN TO LAVOISIER.

Class I. The Non-Metals,	Class II. The True Metals,	Class III. The Semi-Metals,
Oxygen, or vital air.	Gold.	Arsenic.
Hydrogen, or inflammable air.	Silver.	Antimony.
Nitrogen.	Copper.	Bismuth.
Chlorine.	Lead.	Zinc.
Carbon.	Iron.	Cobalt.
	Tin.	Nickel.

Since the time of Lavoisier, thanks to the labours of several generations of chemists, we have now become acquainted with sixty-four elementary substances, existing in varying proportions in the air, the water, and the solid crust of the earth. Here is a list of these elements, some of which are widely distributed;

others are marked "common and useful;" while a long list at the bottom is marked "rare elements":—

TABLE OF THE ELEMENTS KNOWN AT THE PRESENT TIME.

MOST WIDELY DISTRIBUTED.

Aluminium.	*Hydrogen.	Oxygen.
*Bromine.	*Iodine.	*Phosphorus
Calcium.	Iron.	Potassium.
*Carbon.	Magnesium.	*Silicon.
*Chlorine.	Manganese.	Sodium.
*Fluorine.	*Nitrogen.	*Sulphur.

COMMON AND USEFUL.

Antimony.	Copper.	Silver.
Arsenic.	Gold.	Strontium.
Barium.	Lead.	Tin
Bismuth.	Mercury.	Tungsten.
*Boron.	Nickel.	Uranium.
Chromium.	Platinum.	Zinc.
Cobalt.		

RARE.

Cadmium.	Lanthanum.	*Selenium.
Cæsium.	Lithium.	Tantalum.
Cerium.	Molybdenum.	*Tellurium.
Didymium.	Niobium.	Thallium.
Erbium.	Osmium.	Thorium.
Gallium.	Palladium.	Titanium.
Glucinum.	Rhodium.	Vanadium.
Indium.	Rubidium.	Yttrium.
Iridium.	Ruthenium.	Zirconium.

Many of the substances named in the third division are but slightly known, and have been experimented on by only a few chemists, and most of these have as yet not been applied to any useful purposes in the arts or manufactures; still we cannot tell what a day may bring forth, and even the rarest of these elements may at any time prove to be a useful and important body in ways not dreamt of before.

The next important fact which I wish to bring before you is the fixedness of the composition of chemical compounds. How would it be possible to have a science of chemistry if the composition of chemical substances varied from time to time? We know that if we once make an accurate determination of the quantity of lead which can be got out of a certain weight of

this white sugar of lead, or of the mercury which we can obtain from this red calx, we need not trouble ourselves to make a second determination. By one accurate experiment we can be certain as to the result, for experience has shown us that the same chemical compound always contains its constituent elements in the same unvarying proportion; and this important conclusion is one which can be arrived at by experiment alone.

It is only by experiment, or by putting questions to nature, that she divulges her choicest secrets. Of all the means which have assisted chemists in arriving at these conclusions, the help afforded by the *balance* is the most important. The first man who employed the balance for the purposes of research appears to have been Joseph Black, professor of chemistry, first in Glasgow and then in Edinburgh. Black's balance is now to be seen in the valuable and interesting exhibition of scientific instruments at South Kensington; and although Black's instrument was not a delicate one, simply consisting of a rough pair of scales, nevertheless, with it he made investigations and determinations which have an undying interest.[1] After Black came Lavoisier, and it is generally stated that Lavoisier was the first to introduce the balance. This, however, was clearly not the case; for although he employed the balance largely, we are indebted to Black for its first introduction. In writing to Black in 1790, Lavoisier acknowledges the claims of the Scotch chemist in the following remarkable words:—

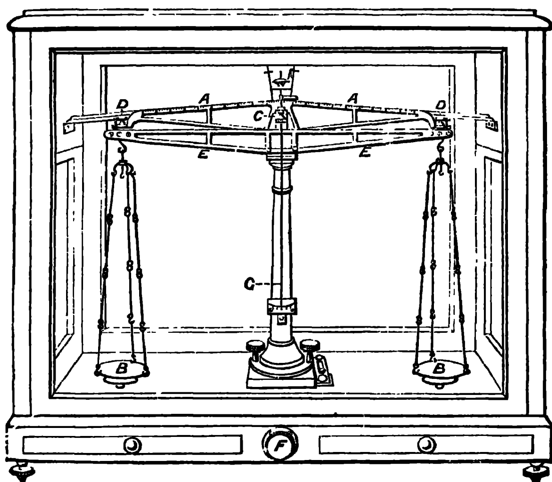
"Il est bien juste, Monsieur, que vous soyez un des premiers informés des progrès qui se font dans une carrière que vous avez ouverte, et dans laquelle nous nous regardons tous comme vos disciples."

This is a clear recognition of Black's claim to the merit of discovering the method of investigation which Lavoisier afterwards employed.

From what I have said, the necessity for experimentation—in order that we should attain a knowledge of the chemical properties of the substances of which the earth is made up—will be evident to you all. I may illustrate this in a very simple way. Suppose, for instance, that we have here—as is indeed the case—a series of jars filled with colourless, invisible gas, which, so far as we can tell, by merely looking at them seems to be of one kind. If, however, we interrogate Nature, that is, if we

[1] *Experiments upon Magnesia, Alba, Quicklime, and other Alkaline Substances.* Edinburgh, 1755.

make an experiment, as to the nature of the gas contained in these jars, we shall find that, although apparently the same, these gases are in fact very different substances. If I take this taper and insert it into the jars, this difference will soon become visible. When I dip the taper into the first jar, we do not notice any apparent change, for the flame of the candle burns much as it did before. If I put the taper into the next bottle there is a distinct change, for the taper is at once extinguished. When I place the extinguished taper, having, however, its wick still red-hot, into the third jar, you will see another change, for



Here you have (FIG. 4) a figure of a chemical balance.

the taper is instantly rekindled, indicating by the brilliancy of the combustion the existence of a totally different gas. Again, I will drop the burning taper into the fourth jar, and you see that the colourless gas itself takes fire and burns, although it extinguishes the flame of the candle. I can show you in other ways, by weight as well as by sight, that these gases differ from one another. For here I can pour one gas like water from one vessel to another; whilst in another case I can pour the gas upwards, because it is lighter than air. These are properties of gases, then, which can only be learned by experiment.

Understanding, then, that bodies always have a fixed composition, let us proceed a step further, and ask ourselves whether there is such a thing possible in Nature as a loss of matter. If I take this piece of watch-spring, kindle the string tied to one end, and then plunge it into a jar filled with oxygen, you see that the watch-spring burns, and in burning it will deposit a quantity of red-hot oxide. Observe the brilliancy with which the iron is now consumed, but also notice that the white-hot molten globules which fall down indicate what has become of the watch-spring, which no longer exists as such, but instead of it we have some quantity of a brown deposit, which we know as "rust of iron." If we next take as an example of chemical change that which occurs when a common candle burns, we cannot so readily observe what becomes of the materials of the candle. That the wax and the wick, the materials of which the candle is composed, disappear is certain. The question is, have they been destroyed, or have they only undergone a change and become invisible to our eyes? By this very simple arrangement we have the means of answering this question, for we can collect all the products of the combustion of the candle, the carbonic acid and the water, and we can show that these products weigh more than the candle does, just as the iron-rust produced in our last experiment weighs more than the watch-spring did. I have here a little taper, which is placed in a tube (Fig. 5), and this tube is placed at the end of the beam of a balance, which is arranged to be in exact equilibrium. Now I am about to burn the candle, and I shall collect the products of its combustion in the white caustic soda contained in the upper part of the tube (Fig. 5), so that nothing will escape but the air which has passed through the flame in the burning of the candle. I must have a current of air passing through in order to make the candle burn, and this I obtain by allowing the water to run out of this oil-can, the top of which is connected with the tube. The candle is now burning, and the question is—What has become of the wax and the wick? I want you to see that the materials of the candle, instead of having been destroyed, exist under another form—that of carbonic acid and water, which products have been laid hold of by the caustic soda and prevented from escaping. At the end of our experiment we shall find that the candle has lost half its weight, and that the other end of the balance is heavier by the oxygen of the air which the component parts of the atmosphere have taken up. You observe that this side of

the apparatus is heavier than it was before, showing that in the case of a burning candle there is no such thing as a loss of matter. And this conclusion as regards this one case of chemical change has been proved by thousands of careful experiments to apply to every other case which has come under the eyes and hands of the chemist.

Let us next consider for a moment the distribution of the elementary bodies. In the first place we find that while only

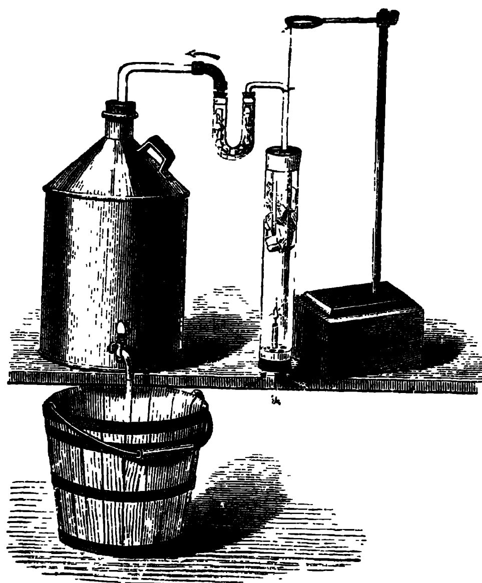


Fig. 5.

about four elements are found in the air, about thirty exist in the water of the ocean, whilst the rest are found in the solid earth. We are, however, quite unacquainted with any law regulating their distribution, but we find that certain elements are universally distributed whilst others occur most rarely. Thus, oxygen is found in almost every solid as well as in water and air, constituting (as is seen from the following table) about one-half of the solid crust of the earth.

Here you have a table giving the average composition of the solid earth's crust so far as the primary rocks are concerned. It shows that the bulk of the earth's solid body is made up of only eight elements, the remainder existing in the earth in much smaller quantity.

COMPOSITION OF THE EARTH'S SOLID CRUST IN 100 PARTS BY WEIGHT.

Oxygen	44·0 to 48·7	Calcium . . .	6·6 to 0·9
Silicon	22·8 to 36·2	Magnesium . .	2·7 to 0·1
Aluminium .	9·9 to 6·1	Sodium . . .	2·4 to 2·5
Iron	9·9 to 2.4	Potassium . . .	1·7 to 3·1

Respecting the composition of the whole mass of the earth we are as yet, as I have said, to a great extent ignorant, and a little consideration will show why this is the case. Imagine, if you please, that C (Fig. 6) represents the centre of the earth, and that the lines AC, and BC, are radii to the surface of the earth. Then the black line, AB, represents the portion of the earth's crust known to man. The greatest height to which man has ascended by means of a balloon, and the greatest depth to which he has descended by means of a mine, are included in the breadth of that dark line, so that all beyond this black line towards the centre of the earth is to us, so far as man's penetrating power is concerned, terra incognita. But although we cannot get there, yet we have means of learning something about the composition of these internal parts, because we can examine the chemical nature of the lava which is thrown up by volcanoes, and we can also examine the salts held in solution by spring water which comes from a great depth below the earth's surface.

Many of the hot deep mineral springs, such as those at Bath and Buxton, bring up to the surface various compounds and elements in a state of solution, the nature and properties of which can be examined by chemical means. But beyond these two means, we have at present no direct way of ascertaining what kind of elements or compounds exist at a great depth below the surface of the earth.

In the year 1772 a very interesting series of measurements was made in Scotland on a mountain known to many of you, called Schehallion. This mountain possesses very steep sides, and it occurred to several mathematicians, Maskelyne especially, that by making plumb-line observations on each side of this steep mountain it might be possible to determine the mean density of the earth, which might in turn guide us to a knowlege of the nature of the portions of the earth to which we

cannot get access. It was found that the plumb-lines hung on each side of the mountain were deviated a little (11″·7) out of the perpendicular by the weight of the mountain. Now if we know the size of the mountain, which can be obtained by a trigonometrical survey, and if we know the specific gravity of the rocks composing the mountain, such as this I hold in my

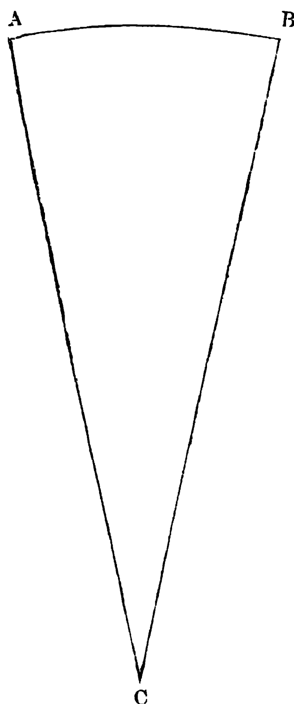


FIG. 6.

hand, and which is two and a half times heavier than water, we can discover the ratio of the attraction of the mountain to that of the earth. And then, we can get the absolute mass of the earth, and knowing its volume, we can get the mean density of the earth, that is to say, we can tell how many times the earth is heavier than an equal bulk of water. This was the first experiment made on this very interesting subject; and the

calculations of Hutton and Playfair from the observations of Maskelyne made the mean density of the earth to be 4·713, that is to say, they came to the conclusion that the earth is, roughly speaking, 4¾ times heavier than an equal bulk of water.

Afterwards, another method was employed to determine this fact, namely, by means of a torsion balance, an instrument used by Cavendish, by means of which he found that the density of the earth was 5·48, or about 5½ times heavier than water. Other observations have been made on this subject, the best of them being the result of a Commission appointed by the Government in 1838, in which the astronomer Baily was concerned. His investigations extended from October, 1838, to May, 1842, and he came to the conclusion, which we may regard as the most accurate one which has yet been obtained, that the mean density of the earth was 5·66, or rather more than 5½ times heavier than water. It is worth remembering that Newton, in his great work, the *Principia,* predicted with a most remarkable degree of accuracy that the earth would be found to be between five and six times as heavy as its bulk of water.

You may ask—What has all this to do with the composition of the earth? Well, it has to do with it in this way: that when we descend to the greatest possible depth into the earth and bring up its solid contents, we find that the highest mean specific gravity of the rocks is 2·5, so hence the question arises—What is it that makes the earth so heavy at its centre? It cannot be all made up of granite, because even the enormous pressure of the surrounding parts would not double or treble the density of granite at the earth's centre, and yet we find that the density of the earth is between five and six. Here we come pretty nearly to the boundary of our knowledge, and at this point chemical science cannot help us further; and it is well we should see that there is here for the present a limit to our exact knowledge, and that all beyond must remain more or less conjectured until we are in possession of further experimental data.

As I shall show you in my next lecture, there are a number of elementary bodies whose specific gravity is very much greater than that of granite. Many of the metals, for instance, are much heavier than granite; and we can suppose, if we like, that the interior portions of the earth are composed of metals.

Perhaps Mr. Lockyer may continue these considerations, and he may inform you that there are other grounds for believing

that the interior of the earth may be largely composed of unoxidized and heavy metals.

Then you may ask—Is the inside of the earth fluid or solid? Even in such an apparently simple question as this we are still in some degree of doubt. You may think this is strange, because we find volcanoes throwing out lava, which is liquid rock, and because we find much other geological evidence to show that solid rocks, such as basalt and trap, have been protruded as molten masses within recent geological epochs; but it has recently been shown by Mr. Mallet that the fact of volcanoes throwing out liquid rock may not be inconsistent with the view that the earth as a whole is solid. Mr. Mallet's investigations go to prove that this liquefaction of the rocks which we observe may be produced at no very great depth from the earth's surface by the shifting and rubbing together of the rocks, owing to cracking due to the alteration of the temperature, just as boys at school rub a button on the bench until it is hot, when they often place it on to their neighbour's cheek. Applying the laws of the Mechanical Theory of Heat to this problem, Mr. Mallet believes that the friction of the rocks, caused by the secular cooling of the earth and the consequent shrinkage, is a sufficient and a satisfactory explanation of the occurrence of the high temperature of volcanic action.

Sir Wm. Thomson,[1] also, than whom no one is more capable of expressing an opinion, decides in favour of the earth's solidity. He tells us in his address to the Physical Section at Glasgow, that the conclusion concerning the solidity of the earth originally arrived at by Hopkins is borne out by a more rigorous mathematical treatment than this physicist was able to apply, so that the idea of geologists, who were in the habit of explaining underground heat, ancient upheavals, or modern volcanoes, by the existence of a comparatively thin solid shell resting on an interior liquid mass, must now be given up as untenable.

[1] See *Nature*, Sept. 14, 1876.

WHAT THE EARTH IS COMPOSED OF.

LECTURE II.

IN the last lecture I described to you some of the properties of the various kinds of matter of which the earth is composed. I showed you that the various gases which occur on the earth's surface differ from one another in a very remarkable degree. I pointed out to you that some of these gases are light, whilst others are heavy; and that it is only by experiment we can arrive at a knowledge of these facts concerning the nature of terrestrial matter. I wish to illustrate these facts to you once more. We have here two gases differing from each other in specific gravity as well as in other properties; and I think I can make this evident to you by a simple experiment. In this long cylinder, which is apparently filled by a homogeneous colourless gas, we have in fact two gases, one of them heavier than the other. If I plunge this red-hot wick of the taper into the gas at the top of the cylinder, you will observe that it will be rekindled; but that it is extinguished when I push it lower down; whilst it is again ignited if I again raise it into the upper part of the cylinder. Now the gases which compose our atmosphere also differ in specific gravity. Oxygen is somewhat heavier than nitrogen, their weights being in the proportion of the numbers 8 and 7 respectively. Our great townsman, John Dalton, whose discoveries were brought before you in a lecture the season before last, came to the conclusion that in consequence of this difference in specific gravity of the constituent gases of the atmosphere, we should find, in the upper portions of the atmosphere there was a larger quantity of the lighter gas (nitrogen), and in the lower portions a larger quantity of the heavier gas (oxygen). But this was found by experiment not to be the case. It was proved that the air

collected at a great height and that collected at the surface of the earth at the same time, exhibited exactly the same proportions between their constituent parts. This fact we explain by the circumstance that the winds move the gases of the atmosphere constantly one among another. Moreover, we know that gases possess the property of diffusion, by virtue of which the particles of one have a tendency to diffuse amongst or interpenetrate those of another gas, thus rendering the atmosphere throughout of one constant composition, so far as regards these two principal elements, nitrogen and oxygen.

In like manner, liquid substances differ from one another in their weight. We know very well that oil will swim on the top of water. And many experiments can be made to illustrate this fact, that liquids differ from one another in their relative weights. In the following table you find the weight of some of the most common liquids compared with that of the same bulk of water taken as the unit, and these relative weights are termed the specific gravity of the liquids.

TABLE OF THE SPECIFIC GRAVITY OF LIQUIDS.

Water	1·00
Mercury	13·598
Sulphuric Acid	1·841
Nitric Acid...	1·510
Hydrochloric Acid...	1·240
Sea Water	1·026
Absolute Alchohol	0·803
Ether	0·723

In like manner solids differ widely from one another in specific gravity.

On the next page you have a table containing the specific gravities of most of the metals.

In the first column of this table you find the names of the metals, in the second a series of numbers representing how many times each metal is heavier than the same bulk of water, and that number you know is termed the specific gravity; whilst in the third column we have black bars of different lengths, exhibiting the size of the various bars of metal possessing all the same weight.

TABLE OF THE SPECIFIC GRAVITY OF THE METALS,

SHOWING THE BULKS OF THE DIFFERENT METALS WHICH POSSESS EQUAL WEIGHTS.

Platinum	21·5
Gold	19·5
Uranium	18·4
Tungsten	17·6
Mercury	13·59
Thallium	11·58
Lead	11·45
Palladium	11·30
Silver	10 50
Bismuth	9 90
Copper	8·96
Nickel	8·80
Cadmium	8 70
Molybdenum	8·63
Cobalt	8·54
Manganese	8·00
Iron	7·79
Tin	7·29
Zinc	6 86
Antimony	6·80
Tellurium	6 11
Arsenic	5·88
Vanadium	5·30
Aluminium	2·56
Magnesium	1·75
Calcium	1·53
Rubidium	1·52
Sodium	0 972
Potassium	0·866
Lithium	0·593

Water =

In the last lecture I stated that the mean specific gravity of the earth was 5·6. I also said that we are at a loss in some measure to account for this, because we do not find, so far as we have gone down into the earth, that we come across any of these metals; but we find only substances like granite, which have a specific gravity of only 2·5 or 3. Whether or not some of these heavy metals occur in the interior of the earth, at a lower point than we have yet reached, is, as I reminded you in my last lecture, still a matter of doubt, although the fact of the circulation of truly metallic masses throughout space would rather lead us to believe in the probability of the existence of a similar kind of matter in the earth's interior.

With regard to the elementary bodies, you will observe that on this diagram (see Lecture I, page 8) I have marked fifteen of these elementary substances with a cross. These we term non-metals, as opposed to the remaining forty-nine, to which

we give the name of metals. Some of these non-metals are gaseous, such as oxygen and hydrogen, nitrogen and chlorine; some of them are solid, such as carbon. Some of the gases, such as chlorine, can be condensed by great cold, or by exposure to great pressure to liquids, whilst others, such as oxygen, have not been liquefied although exposed to very great pressure.

We may now proceed with our investigation, and ask ourselves, Have we reason to believe that in process of time some or all of these substances may possibly prove capable of being decomposed into other substances? Are these sixty-four substances truly elementary bodies? In this case, of course, we can only argue from analogy, and from what has already taken place. We must look back into the history of our science and inquire if any of the substances which were supposed, up to a certain time, to be elements, have by subsequent research been found to be compound bodies. As an illustration of this, I would bring before you a discovery which was made in the year 1808 by Sir Humphry Davy. In the *Bakerian* lecture for that year, which was read before the Royal Society on November 19, 1807, Davy brought forward a most important discovery which he had just made on the decomposition and composition of the fixed alkalies. This white solid substance which I hold in my hand has long been known as the alkali potash. It is obtained from the ashes of land-plants by boiling the ashes in pots This substance has long been known for its peculiar alkaline properties. Another alkali, obtained from the ashes of sea-plants, is soda. The term alkali was first applied by the Arabians to the carbonate of soda found in the ashes of sea-weed, and afterwards to the carbonate of potash, obtained by burning land-plants, and both these substances were for a long time considered to be identical, whilst the *caustic* alkalies obtained from the *mild* or carbonated alkalies were considered by all chemists to be elementary or simple bodies. Now in the experiment to which I refer, Davy showed that these substances, potash and soda, which up to that time had been supposed to be elementary bodies, are really not so, but are compound substances, that is, bodies which can be split up into two separate things, namely a metal potassium and colourless oxygen gas. I will first read to you a few words giving the gist of Davy's discovery as related by himself in the Philosophical Transactions for 1808. He says:—

"A small piece of pure potash, which had been exposed for a few seconds to the atmosphere so as to give conducting power to the surface, was placed upon an insulated disc of platina connected with the negative side of the battery, of the power of 250 of 6 and 4, in a state of intense activity, and a platina wire communicating with the positive side was brought into contact with the upper surface of the alkali. The whole apparatus was in an open atmosphere. Under these circumstances a vivid action was soon observed to take place. The potash began to fuse at both its points of electrization. There was a violent effervescence at the upper surface; at the lower or negative surface, there was no liberation of elastic fluid; but small globules having a high metallic lustre, and being precisely similar in visible characters to quicksilver, appeared, some of which burnt with explosion and bright flame, as soon as they were formed, and others remained, and were merely tarnished, and finally covered by a white film which formed on their surfaces. These globules, numerous experiments soon showed to be the substance I was in search of, and a peculiar inflammable principle the basis of potash. I found that the platina was in no way connected with the result, except as the medium for exhibiting the electrical powers of decomposition. The phenomenon was also independent of the presence of air. I found that it took place when the alkali was in the vacuum of an exhausted receiver."

I hope to show you this experiment, performed just as Davy did it. I take a piece of white alkali, potash, moisten it by dipping it into water for a moment, and bring it under the influence of a powerful current of electricity, and as soon as I do so you observe that this white substance is decomposed into its two elementary constituents, oxygen and potassium.

The bright luminosity which you notice is due to the burning or combustion of the metal potassium which is liberated at the pôle in contact with the zinc of the battery. The white fumes which ascend are the products of the combustion of the potassium which has united with the oxygen of the air with the re-formation of potash.

In order to impress you still more forcibly with this fact, I will throw a small bit of potassium upon water. This body combines with oxygen with such avidity that when I throw it on the water, which you know is a compound of oxygen and hydrogen, the potassium will take hold of the oxygen of the water and liberate the hydrogen, and such heat will be

formed by that liberation of the hydrogen, that we shall see that it takes fire and burns.

Quickly following upon Davy's discovery of the composition of potash came of course the discovery of the composition of soda, and soon after came the decomposition of lime, which Davy also showed was not an elementary body, as had



hitherto been believed, but in fact an oxide, being a compound of the metal calcium with oxygen gas.

That hydrogen gas is actually evolved by this action of potassium, and of sodium upon water, I shall be able to show you; for I will collect the gas in this tube, instead of allowing it to burn, and then show you that the colourless gas

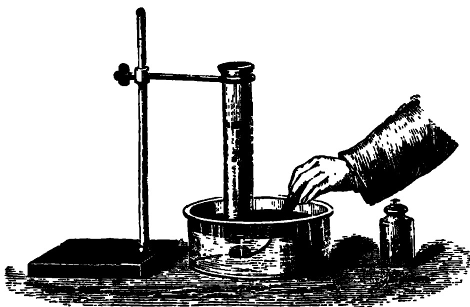


Fig. 8.

thus collected is hydrogen gas. I throw a bit of sodium on the water, and bring it under the surface of the water, so as to collect the hydrogen gas which is evolved in this tube.

I can next show you that the gas is hydrogen, by bringing a flame into contact with it, when it burns with a pale flame, which is of a yellow tint, owing to the presence of soda.

I have here a beautiful specimen of the metal sodium, the substance which is the metallic basis of soda. Here again this beautiful, bright, shining metal which we know as magnesium is the metallic basis of the earth magnesia, for this earth can also be split up into a metal and into oxygen gas. When I burn this metal you see that we get a bright white light which is due to the combustion of the magnesium and its combination with the oxygen gas of the air. The white powder which you see falling down is the oxide of the metal, formed by the union of the metal with oxygen.

Since Davy's time several other substances supposed to be elementary have been proved to be compounds. These have been chiefly among the rarer elementary bodies. I have here the means of explaining one of these interesting cases. This cube we will suppose for the moment to be a metal to which the name of "vanadium" is given. It was believed that this body was really a metal; but a few years ago it was found that two different things could be obtained from this, viz., a true metal and oxygen gas; so that the substance which was considered to be an element really proved to be a compound, with oxygen inside it, as it were. I may illustrate this to you by taking out from the inside of this green box of supposed metal, this red box labelled oxygen, which had hitherto escaped our observation because it was hidden inside the green box. Here you see a list of four substances, titanium, uranium. niobium, and vanadium, all rare bodies which were believed by the discoverers to be metals, but which have since been shown to be compound bodies.

TITANIUM.	URANIUM.	NIOBIUM.	VANADIUM.
Wollaston ... 1823 Wohler... ... 1849	Klaproth ... 1789 Peligot... ... 1849	Hatchett ... 1801 Rose ... 1842–64 Marignac ... 1865	Sefström and Berzelius... 1831 Roscoe... ... 1867

Then the question arises—Looking back at the history of our science, as we have been doing, is it possible that any of the substances which we now speak of as elements, may hereafter turn out to be compounds? With regard to this, our conclusions must be conjectural, but we may remember that certain of these elementary bodies possess common or analogous properties—certain family likenesses. I will select one out of many examples of elementary groups with

which we are acquainted. We have here three elementary bodies: one of them, chlorine, is a gas; another, bromine, is a liquid; and the third, iodine, is this black solid body. The bromine and iodine can be converted by heat into gases, each of which is distinguished by its peculiar colour. Here you see the beautiful purple colour of iodine gas, here the dark reddish-brown colour of bromine gas, compared with a beautiful greenish-yellow colour of chlorine. These substances, as I said, resemble one another very closely in their properties. I will next show you that this is the case. I will take a small quantity of iodine, a small quantity of bromine, and a cylinder filled with chlorine, and I will bring into contact with each of these substances a small piece of the element phosphorus. You will then see that each of these substances exhibits the same properties with regard to the phosphorus with which each of the three elements combines with evolution of light and heat. This indicates, so far as phosphorus is concerned, that these three substances have similar properties. The phosphorus, you see, takes fire and is burning in the chlorine gas. The same thing will take place when I bring a drop or two of bromine into contact with the phosphorus. You see that the phosphorus has taken fire and is burning. I will now show you that the same result occurs with the phosphorus and the iodine.

In other respects, too, these three bodies exhibit remarkable and as yet unexplained analogies. Bromine, both in its chemical and physical characters, stands half-way between chlorine and iodine. In its volatility, in its specific gravity, as well as in its power of chemical union, bromine is a sort of half-way house between the other two. In like manner the number representing the weight with which bromine enters into chemical combination is almost exactly the mean between the similar numbers of chlorine and iodine. Thus whilst 35·5 and 127 are the combining weights of chlorine and iodine respectively, 80 is the combining weight of bromine, the arithmetic mean of the two other numbers being 81.

Now, up to the present time this solid iodine, this liquid bromine, and this gaseous chlorine are elementary substances, because we have never succeeded in getting the one from the other, or in splitting any one of these into two different things. We have as yet not succeeded in turning iodine and chlorine into bromine. But no one who is acquainted with the properties of these substances would be surprised to learn

that bromine had been shown to be in some way connected with chlorine and with iodine; and therefore although we cannot prove it, yet from studying their properties and knowing the nature of the several elements, modern chemists do not consider the problem of the transmutation of the elements to be an absurd one, although we may look to a different kind of solution of the question from that aimed at by the old alchemists.

The next question which attracts our attention is also one of great interest—the question, namely, whether these sixty-four elementary bodies make up the sum total of the elementary constituents of our globe, or whether, in all probability there are other elements existing which have up to the present time eluded our grasp. Here, again, we can only argue from analogy. We can only look back at the history of our subject and see whether new elementary bodies have been discovered, and then ask ourselves is it likely that other new ones still remain unknown to us, but which will be revealed by subsequent investigation?

I mentioned in the last lecture that during the lifetime of Lavoisier only seventeen substances were known to exist as elementary bodies; whilst since his time discoveries of new elementary bodies have been made until the number known to us is sixty-four.

In what way have these new elementary bodies been discovered, and in what way may we look forward to the discovery of new substances now unknown? I will illustrate this to you by one or two simple experiments, and thus indicate to you how in the last few years new elements have been found.

In the year 1860 Professor Bunsen, one of the greatest of living chemists, was busy investigating the properties of a peculiar mineral water which springs out at Baden-Baden in Germany, and having collected a large quantity of the residue from this water, he discovered in it the existence of two new alkaline metals, which up to that time had been overlooked. These two new alkaline metals were discovered by Bunsen by the help of a new method of investigation, a method which I dare say many of you are acquainted with, but the principles of which I will briefly allude to—the method of spectrum analysis.

It has been long known that when certain substances are brought into a colourless flame, such as you see here, they

have the power of imparting to the flame a peculiar colour; but it has only recently been observed that when these coloured rays are examined more accurately than we can do simply by the naked eye, when this beautiful purple flame which you see burning here is examined by means of a prism in the instrument termed the spectroscope, one of which you see on the table (Fig. 10), we have the means of detecting the presence of small quantities of matter which have hitherto altogether eluded our grasp.

This spectroscope consists of a prism (*a*, Fig. 10) fixed upon

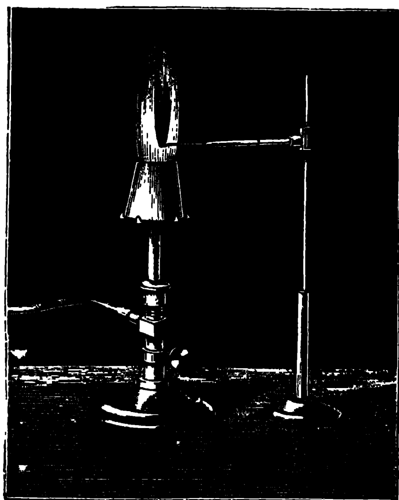


FIG. 9.

a firm iron stand, and a tube (*b*) carrying the slit, seen on an enlarged scale in Fig. 10 (*d*), through which the rays from the coloured flame (*ẽ* and *e*) fall upon the prism being rendered parallel by passing through a lens. The light having passed through the prism, and having been refracted or split up into its constituents, the differently coloured rays are received by the telescope (*f*) and the image magnified before reaching the eye. The rays from each flame are made to pass into the telescope (*f*), one set through the uncovered half of the slit, the other by reflection from the sides of the small prism (*e*),

through the lower half; thus bringing the two spectra into the field of view at once, so as to be able to make any wished-for comparison of the lines.

In this way Bunsen was enabled to prove that in the residue from the alkaline deposits in the waters of Baden-Baden there was present a substance not hitherto observed, and to this substance he gave the name of rubidium, from *rubidus*, dark red, whilst to the other alkaline metal he gave the name cæsium, from *cæsius*, sky colour. I will next show you the spectra of these metals on the screen. I have here the means of producing the bright light of the electric-arc (Fig. 11), and by casting these rays first through the slit B, then through the lens D, and lastly through the two prisms E and E′ we

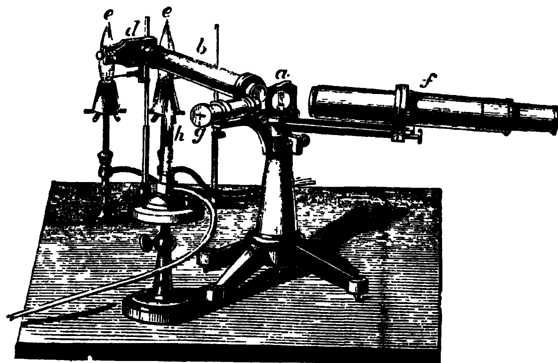


FIG. 10.

obtain on the screen the beautiful bright band, which you see exhibits all the rays of colour from red to violet, and is therefore called a continuous spectrum.

This is produced by white-hot carbon poles, and any white-hot solid body will produce the same effect. If, however, instead of allowing the light to proceed from the carbon poles, I examine the rays which come off from the purple-coloured rubidium flame which is here burning, I obtain a totally different effect in the spectrum, for I produce what is known as a broken spectrum; that is to say, instead of having an unbroken succession of colours, I have a series of bright lines which are different for every one of the sixty-four elementary bodies. The bright bands which were observed by Bunsen in the

Baden-Baden mineral water were different from any which had hitherto been noticed, and were produced by the presence of a new element.

I will now bring on to the carbon pole a small quantity of

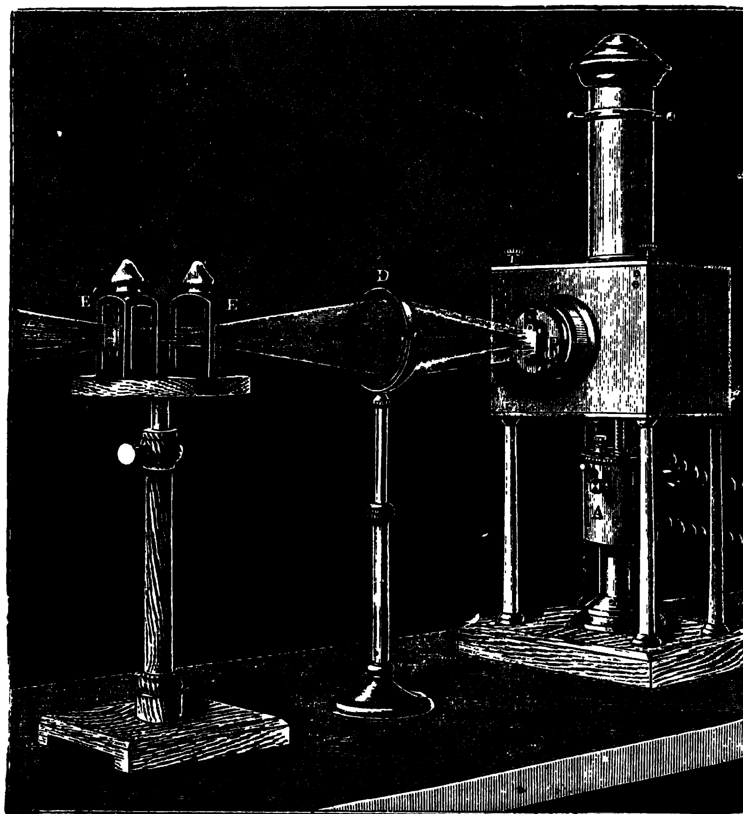


FIG. 11.

a rubidium salt, and you will then see the effect which this is capable of producing. You will notice that we have a spectrum totally different from that which we have had before. Here we get a distinct series of bands, one in the red being

very characteristic, and these are indicative of the presence of rubidium, and are produced by no other known substance.

A year after Bunsen's discovery, Mr. Crookes was able to prove, by means of spectrum analysis, the existence of a third substance, to which he gave the name of thallium. I can now show you the grounds which led Mr. Crookes to assert the existence of a new metal, which had hitherto been overlooked. You see on the screen a green band, which is given by no other substance but thallium.

A fourth metal was discovered by the same means, a metal to which the name of indium was given, because it exhibits two very beautiful lines in the indigo. Here you see the bright lines characteristic of this metal, an extremely rare substance, discovered by Messrs. Reich and Richter. No other substance known will produce these peculiar bands of indigo-coloured light.

A fifth new element has quite recently been discovered by means of spectrum analysis. To this body its discoverer, M. Lecoq de Boisbaudran, has given the name of gallium. Unfortunately this substance has hitherto been found in such minute quantities, that I have none to show you.

From what I have said you will conclude this instrument, the spectroscope, has become one of the chemist's most potent assistants, and that we have only to go on examining by its aid the composition of terrestrial matter with still greater care, and apply to the examination means of still greater accuracy than we have hitherto done, in order to discover a still larger number of elements, and thus to add to the stones of which the edifice of our science is constructed.

The question next arises—Have we any evidence respecting the chemical composition of the other heavenly bodies? The most evident means which we have of examining the composition of matter existing in space beyond our earth, is by analysing those singular and interesting bodies which fall from time to time on the earth's surface, namely, the meteorites, or falling stars, as they are commonly termed. I have in my hand such a meteoric mass. This piece of stone differs both in appearance and physical characteristics from ordinary rock, such as the earth is composed of. If we cut into these meteorites we find that they are made up either of masses of bright shining metal, chiefly metallic iron, or of stony matter interspersed with little nodules, or spots of metal. But although their physical characteristics are totally different

from those which belong to terrestrial matter, yet, when we come to examine their chemical characteristics, we find that these are altogether the same as the chemical characteristics of terrestrial matter, in other words, when we come to analyse these meteorites, we find that they really consist of the same elementary bodies as we find compose the mass of the solid earth's crust, and up to the present time, no new elementary body has been found on any one of these meteorites.

ANALYSES OF METALLIC METEORITES.

	ANALYST							
	Smith	Field.	Forch-hammer	Urico-Echea.	Urico-Echea.	Pugh.	Pugh	Berge-mann.
Iron...	85·54	87·80	93 39	81·20	90·40	90·43	87·89	85·42
Nickel	8·55	11·88	1·56	15 09	5·02	7·62	9·05	9·73
Cobalt	0 61	—	0 25	2 56	0·04	0·72	1 07	0·44
Copper	0 03	—	0·45	} —	trace	0·03	trace	0 03
Tin	—	—	—					
Manganese	—	—	—	—	—	—	0·20	—
Magnesia	2 04	—	—	—	—	—	—	—
Chromic oxide	0·21	—	—	—	—	—	—	—
Sulphur	—	—	0·67	—	trace	0·03	—	0 84
Silicon	—	—	0 38	—	—	—	—	—
Silica	3 02	—	—	—	—	—	—	—
Phosphorus	0·12	0·30	0·18	0 09	0·16	0·15	0·62	—
Phosphide of Iron and Nickel	—	—	—	—	2·99	0·56	0·34	1 05
Carbide of Iron	—	—	—	—	—	—	—	0·33
Chrome Iron	—	—	—	—	—	—	—	1·48
Admixed Minerals ...	—	—	—	—	1·11	} 0·34	0·22	—
Carbon	—	—	1·69	—	—			
Residue	—	—	—	0 95	—	—	—	—
	100·12	99·98	98·57	99·89	99 72	99·88	99·39	99·32

Here we have a list of the constituents of some of the best known meteorites; you see that they contain iron, nickel, cobalt, copper, tin, manganese, magnesium, sulphur, phosphorus, and carbon. These are all substances which we know of as building up the solid mass of the earth, and we, therefore, come to the conclusion that the particular kinds of matter which we know to exist on our earth, are also found in the masses which circulate in space and fall down upon the earth, so that the materials of which the universe is built up, so far as our evidence reaches, would appear to be homogeneous, and not different in each different heavenly body. Nor is it indeed impossible that the earth's interior mass may even

partake of the physical nature of these metallic meteorites, and that if we could obtain a portion of matter from a great depth below the earth's surface we should find it exactly corresponding in structure as well as in chemical composition with a metallic meteorite, and the existence of such interior masses of metallic iron may go far to explain the well known magnetic condition of our planet.

In the next course of lectures Mr. Lockyer will, I have no doubt, go into this subject much more fully than I am able to do, and I leave it to him to explain how the conclusion which we chemists have arrived at respecting the composition of extra-terrestrial matter from our examination of meteoric masses has been supplemented and extended by spectrum observations on the sun and fixed stars.

WHAT THE EARTH IS COMPOSED OF.

LECTURE III.

I HAVE this evening to open out to you a new chapter in the history of the chemical elements, and one which, if we can read it aright, is of great interest as well as of great importance. I have on this table three very different substances: a piece of charcoal, a piece of graphite or plumbago, and here I hold in my hand what you will be pleased to consider the largest diamond in the world. I need scarcely say that this is not a real diamond, but it is an exact model of the Koh-i-noor made of glass. Now these three substances, which, in their physical appearance and uses are so different, are, as I shall show you to-night, chemically one and the same body. Charcoal, graphite, and diamond, are, so far as their chemical properties are concerned, all composed of pure carbon.

In the two previous lectures of this course I pointed out to you some of the most important general properties or characteristics of the chemical elements taken as a whole. To-night I wish you to confine your attention to this one elementary substance—carbon—for we shall find that in considering its properties we have ample means of awakening our interest in becoming acquainted with some of the most striking phenomena of our science.

First of all, we will, if you please, take up the subject of the diamond. This beautiful bright, white, colourless substance was prized highly as a gem by the ancients, but as diamond is the hardest of known substances, the art of diamond-polishing was in olden time not understood, and diamonds could not be cut and polished until the year 1476, when Louis von Berguen first showed how this might be accomplished by means of diamond powder itself; for although the diamond is the hardest of all substances, yet, of course, we can crush it by

means of a blow on an anvil or by pounding it in a mortar, and this diamond powder, or diamond dust, is the only substance that will cut diamond. As the ancients were unaware of this means of polishing the diamond, they only prized those diamonds as gems in which the natural crystalline faces of the diamond were bright and transparent.

Here you see a drawing representing the crystalline form in which the diamond usually occurs.

The other form of crystalline carbon, viz. graphite, does not crystallize in this particular form in which the diamond occurs, but in quite another form, and thus another essential difference between these two forms of carbon becomes apparent.

The history of the diamond, so far as its chemical character is concerned, is one of great interest, and one upon which we

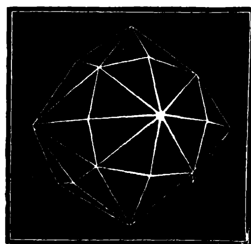


Fig. 12.

may with advantage spend a few minutes. The first hint or observation we find recorded respecting the probable chemical nature of the diamond was given to us by the immortal Newton, who from an examination of the character of the diamond, and observing its high powers of refracting or bending light, which gives to the gem its peculiar beauty and value, and observing that other substances which are known to be combustible likewise possessed this power, concludes that in all probability the diamond will ultimately be found to be a combustible body. Thus in his celebrated *Treatise on Opticks*,[1] speaking of this refractive powers of substances, Newton says: "Again, the refraction of camphire, oyl-olive, lintseed oyl, spirit of turpentine, and amber, which are fat, sulphureous, unctuous bodies, and a diamond, which probably is an

[1] London, 1704, second book, p. 75.

unctuous substance coagulated, have their refractive powers in proportion to one another as their densities, without any considerable variation." It was not, however, till the year 1694 that the academicians of Florence, under Cosmo the Third, Duke of Tuscany, made an interesting experiment, which attracted the general attention of the civilised world, on the possibility of evaporating the diamond. In Galileo's tribune at Florence you may see the identical lens, or large burning-glass, which was employed in the year I have named by the Florentine academicians for the purpose of ascertaining what effect would be produced by placing a quantity of diamonds in the rays of the sun brought to a focus by this large lens. They found to their astonishment that rubies, emeralds, and other precious stones withstood the high temperature to which they were exposed in the concentrated rays of the sun in this burning-glass, remaining quite unaltered, whilst the diamonds, the hardest of known gems, disappeared altogether. Although this fact of the evaporation of the diamond was verified over and over again, chemists were still unaware of the nature of this evaporation, nor could they explain what took place when the diamond thus disappeared. It was nearly a century after this time, in January 1773, that some further experiments were made on this subject by two French philosophers, Messrs. Darcet and Rouelle. They made a variety of experiments. Placing some diamonds in a crucible inside a very hot furnace, they found that the diamonds disappeared, as they had been previously shown to do when exposed to the sun's rays in the focus of the burning-glass. They came to the conclusion that the diamond is destroyed in a short time when freely exposed to air at a temperature lower than that needed to melt silver; but that when air is excluded, the diamond turns out to be a very refractory substance, that is, it does not easily evaporate. For these same experimenters placed the diamond in a crucible, which they completely filled with powdered charcoal; and then they found that the diamond remained unaltered, although exposed for as long a period as eight days to a temperature of the highest possible kind in a porcelain furnace.

The year after these experiments were made, the great French chemist, whose name I have frequently had to mention, Lavoisier, undertook the examination of this substance, and it is worth while noticing how carefully he went to work, how he proceeded slowly from one step to another in logical

sequence, until he arrived at the true solution of the question he had undertaken to investigate; that is, until he was able to tell us exactly what happens when the diamond evaporates in the free fire, and why it did not do so when surrounded by charcoal. In the first place he evaporated the diamond by means of the burning-glass, and he observed that no visible vapour or smoke was given off, but that the diamond disappeared. He thought that perhaps the solid diamond had in some way been dissolved by the water, and that by evaporating the water which was in the lower part of the bell-jar, in which he burnt his diamond, he might obtain the constituents of the diamond in a solid form, but he found that no solid residue was left on evaporation, and thus no trace of the diamond could be found. His next experiment was that of placing a diamond in the focus of a less powerful lens than the one he had formerly used, so that the diamond was not heated to so high a temperature as before, again placing it, however, in a bell-jar over water. He then found that the diamond when not heated quite so strongly, lost only about one quarter of its weight; it did not disappear altogether, but the remarkable fact was noticed that it became covered with a black substance which Lavoisier describes as being exactly like lamp-black or soot, so that it dirtied the fingers when touched, and made a black mark upon paper. Hence Lavoisier concluded that the diamond is susceptible of being brought under certain circumstances into the condition of charcoal, so that it really belongs to the class of combustible bodies. He was however yet far from having proved his point, and he went on experimenting. He next measured the volume of air in which he was going to burn the diamond, and found it to be eight cubic inches. Then he burned the diamond in this volume of air by means of a lens, and found that the air had diminished to a volume of six cubic inches; thus showing that the air had undergone some change by the combustion of the diamond; and that two out of the eight volumes of air had disappeared. The next experiment he made was to examine the condition of the air in which the diamond had been evaporated. What changes had gone on in the air in consequence of the evaporation of the diamond? After allowing the glass in which he had burned the diamond to stand for four days, he poured clear lime-water into the jar in which the diamond had been evaporated, and he says this lime-water was at once precipitated in the same manner as if it had been brought into

contact with the gas evolved in effervescence and fermentation, or that given off in cases of metallic reduction. Here then he had got on the track of what he wanted. Hitherto the diamond had apparently disappeared, and nothing was found to account for its disappearance; but now he had found that there was something contained in the air in which the diamond was burned which was not contained in that air before.

The next step he took was to examine the white precipitate or powder which was formed, and he found that the substance thus precipitated from lime-water by the air in which the diamond had been evaporated, effervesced on treatment with acid, and evolved what was then known as *fixed air*, but which we now know as carbonic acid gas. Here, then, in his last experiment he completes his proof, showing that exactly the same effects are observed when charcoal is experimented upon instead of diamond. Lavoisier had now run his quarry to earth; he had determined exactly what it is that is formed when a diamond is burned. He has shown that a diamond when burned produces exactly the same substance that is produced when common charcoal is burned, and he, therefore, legitimately concludes that diamond is only another form of the element carbon. The reason that the diamond did not burn in the furnace when surrounded by a mass of charcoal was that the air, or rather the oxygen of the air, could not get to the diamond, because it was kept off by the charcoal, which burned instead of the diamond.

Having thus explained to you what Lavoisier did, let me try to show you the same thing. I have in this bottle a real diamond, not a very large one, but large enough for my purpose. I have in this bottle also some oxygen gas, and I am going to heat the diamond, by means of a galvanic current, in the oxygen gas until it burns, and now you see the diamond burning like a little bright star in the interior of this glass. The diamond is inclosed in a spiral of platinum wire, which I can heat up to whiteness; the wire will then heat the diamond round which it is wrapped, up to the point of ignition. I then take away the heat of the battery and leave the diamond to burn. You will next observe that when the diamond is burned, the clear lime water, which is now perfectly clear and colourless and transparent, will become turbid, exactly as in the case of burning graphite and common charcoal.

I will next burn a bit of graphite, or plumbago. Graphite

is a form of carbon found in large quantities in Cumberland, Siberia, Ceylon and other places, and is used, as you know, for making black-lead pencils. A much higher temperature is required for the purpose of igniting graphite than diamond; but here, as you see, the clear lime-water has become turbid. Next I will burn a bit of charcoal in the third jar, and the same effect is produced upon the clear lime-water. In other words, in these three different substances, we have one and the same elementary body, carbon, so that by their combustion in oxygen, the same gas, namely, carbonic acid gas, is formed.

From the experiments of Lavoisier, although they completely decided the question as to the diamond consisting mainly of carbon, it did not follow that carbon was the sole constituent. Indeed, for many years after these experiments, it was supposed that the colourless gas, hydrogen, is combined with the carbon in the diamond, and this, it was thought, might account in some degree for the difference in the physical properties of the diamond and other forms of carbon. Further experiments were needed to elucidate this point. In the year 1814, Sir Humphry Davy read a paper before the Royal Society, describing the effects which were produced when a diamond was very carefully burned in perfectly dry oxygen gas. In this case no trace of moisture was found, which must have been produced if the diamond had contained hydrogen, whereas in similar experiments made with charcoal, instead of diamond, a production of moisture was invariably observed. But Davy was not satisfied until he had taken some of the chalk obtained from the gas in which diamond had been burnt, and had actually prepared from it black carbon or soot. This he did by heating the white carbonate of lime or chalk with the metal potassium, which then took away the oxygen from the chalk and liberated the carbon in the form of soot. Thus he was able to actually get some lamp-black from the carbonic acid produced by the combustion of the diamond, and this, when strewed in a flame, took fire and burned like common charcoal, so that charcoal was got by Davy from the diamond itself.

I need scarcely say that the diamond has never yet been artificially made; although we should not be surprised some day to hear that such was the case, and that the chemist had been able to change one form of carbon into another, or to prepare the diamond. We do not know at all how the diamond has been made, and all attempts—and they have been many

—to convert the black form of carbon into the colourless crystalline form have hitherto failed.

In many other respects carbon is one of the most interesting of the elementary bodies. In the first place, if we can imagine carbon struck off the list of the elements, if the earth did not contain any carbon, then we must also imagine the world without any organised beings, without animals, without plants, destitute in fact of all forms of vegetation, from the simplest germs to the tree which towers above our heads, destitute also of all forms of animal life, from the most elementary protoplasmic forms, to the most complicated arrangements of nervous and muscular existence. Carbon is, then, an essential element of plants and animals.

That carbon occurs in colourless gases, liquids and solids, I may show you in two or three ways. If I mix this colourless olefiant gas with chlorine gas, and then apply a light, you will see a large black cloud arise, indicating the presence in this colourless gas of carbon which can then be rendered apparent in the solid form. I will next show you that this colourless liquid contains carbon. This is a product of vegetable life, a liquid which we know as turpentine, and if I pour a few drops of this colourless turpentine upon this paper and then plunge it into a jar of chlorine, you see that we get the evolution of light and heat, for the turpentine bursts into a flame and causes a dense smoke, proving that the turpentine contains carbon. We all know that vegetable and animal bodies contain carbon, for when they are partially burnt they are said to be charred. I may show you that white sugar contains large quantities of this black carbon. I have only to pour a little hot water on the sugar to make a syrup of sugar, and then pour on it some sulphuric acid, when we shall see the sugar is converted into a large mass of black charcoal.

Not only because carbon forms the greater part of the structure of all vegetable and animal existence is it important, but it is likewise interesting to the chemist, because, beyond all the other elementary bodies, carbon possesses the power of forming a great variety of compounds; so that the chemist is acquainted with a larger number of carbon compounds than he is of compounds from all the other sixty-three elementary bodies put together.

It is easy to understand that in the progress of science that portion which we may call the destructive portion will be the first to be developed. It is very much more easy to destroy than it is

to build up in matters of science as well as in matters appertaining to everyday life. Consequently, the destructive powers of the chemist were first brought to bear upon matter. It is easy, as I have shown you, to destroy this white powder, sugar, but it is not so easy to build it up again. It is only quite recently that what I may term the destructive chemistry has given place to the constructive. It is especially with regard to carbon compounds that this constructive chemistry has developed the most interesting results. In other words, the constructive chemistry of the inorganic or mineral portion of our science is simpler, and therefore easier and less interesting, than the constructive chemistry of the organic portion, or that

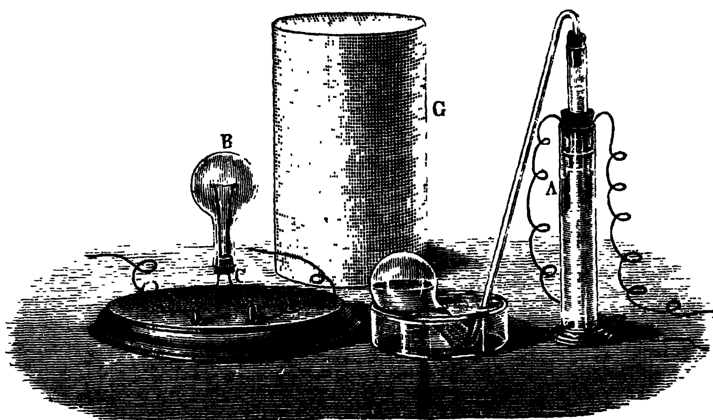


FIG. 13.

which consists mainly of the chemistry of the carbon compounds. I will illustrate this to you by two simple experiments. I have here a little glass bulb, B, Fig. 13, which is filled with oxygen and hydrogen, obtained by the decomposition of acidified water contained by means of the voltameter (A). There is little difficulty in getting these two gases to combine to form water; all I have to do is to pass an electric spark through the gases contained in the bulb, when you hear a loud explosion, which indicates that the particles of oxygen and hydrogen have united together, a drop of water being the result, so that our inorganic constructive chemistry has received an illustration.

Here, again, I have in this second bulb two other gases, termed chlorine and hydrogen, and I hope to obtain the combination of these two gases, not by passing an electric spark through them, as in the former instance, but by exposing them to a bright light by burning near the bulb this piece of magnesium wire. Here we have in a very simple way brought about a combination of the particles of chlorine and hydrogen,

But suppose we now, on the other hand, take a substance such as alcohol—which we know contains carbon, hydrogen, and oxygen,—can we put together the components of alcohol as readily as we can those of water or of hydrochloric acid? Alcohol, we know, is produced by the very complicated process

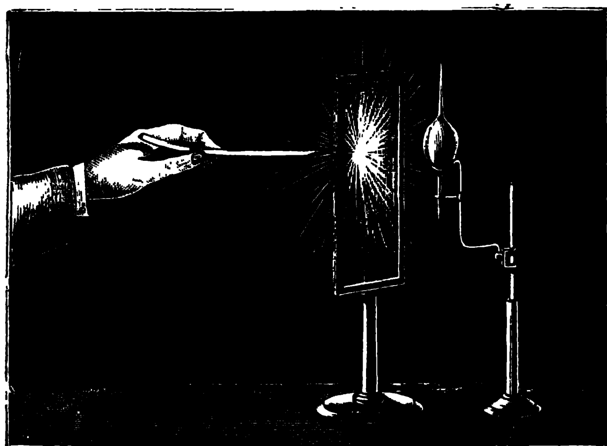


FIG. 14.

of fermentation, and for a long time this was the only method known by which alcohol could be obtained. It is only quite recently that chemists, after years of toil and of preliminary work, have at last arrived at the point of being able to build up alcohol artificially by the union of its constituent elements. Now, however, this can be accomplished not only in the case of alcohol, but in that of a variety of organic compounds. The most interesting examples of constructive chemistry are to be found in that large class of compounds which are the peculiar products of the complex series of phenomena which we designate by the term life. Certain of these substances

have been long known as characteristic products of the animal world, whilst others are always formed by the processes of vegetable life. Now it was for a long time believed that these peculiar substances are produced within the animal or vegetable body according to laws and by actions which man could not artificially imitate.

When, however, in the year 1828, Wöhler first artificially prepared urea, a body especially typical of animal life, from its inorganic sources, carbon, oxygen, hydrogen, and nitrogen, the supposed barrier between purely mineral and animal or vegetable bodies was at once broken down; and since that time so many instances have taken place of the artificial production of naturally occurring products, that all chemists now acknowledge the truth of Liebig's remarkable prediction in 1838, in which he says—"From these researches the philosophy of chemistry must draw the conclusion that the synthesis of all *organic* compounds, which are not *organized*, must be looked upon not merely as probable, but as certain of ultimate achievement. Sugar, salicin, morphine, will be artificially prepared. As yet we are ignorant of the road by which this end is to be reached, since the proximate constituents required for building up these substances are not yet known to us; but these the progress of science cannot fail to reveal."

I will illustrate this to you by showing you on the screen, with Mr. Harrison's kind assistance, the crystallisation of this body, urea, first artificially produced by Wöhler. You now see these needle-shaped crystals shooting over the screen, and observe the lovely colours which they exhibit when examined by means of the beam of polarised light. Here is another body, tartaric acid, a well-known vegetable product, which has been artificially prepared. As you are aware, this substance occurs in the juice of the grape, being deposited in the form of cream of tartar whenever new wine is allowed to stand. This was formerly the only known mode of preparing tartaric acid; but now it may be made artificially, and from carbon, oxygen, and hydrogen we can build up these magnificent crystals of tartaric acid. I might illustrate still farther this same constructive power of modern chemistry with many striking examples, but one or two more must suffice. Here are two strongly smelling oils which all who are within reach of their odour at once recognise as the oil of black mustard-seed, and the oil of garlic. These substances have, of course, long been known as the peculiar products of two plants.

Now we can prepare both these oils artificially, and by this I do not mean that the artificial oils so nearly resemble the natural oils that they can be used for the same purposes, for flavouring food, for example, but that the artificial and the natural oils are identically the same substances, possessing absolutely identical properties, and being indistinguishable by any known means.

One other interesting example of the artificial production of substances I must mention, namely, the artificial preparation of alizarine, the well-known colouring matter of madder. This substance has long been used for producing the fine purple and pink colours so characteristic of Manchester printed goods.

A few years ago this colouring matter was exclusively obtained from the madder root; but now this same colouring principle is made extensively by artificial means from gas tar, and the culture of the madder root may now be said to have come to an end. I have here small quantities of these natural and artificial substances, and I will show you that the colours of these two solutions are absolutely identical. Here then you have one of the latest triumphs of the chemist's constructive skill, which resulted in the creation of a new industry and the complete reorganisation of one of the staple manufactures of the country, all arising out of what appeared to many to be a trivial discovery of two German chemists.

In all these instances of constructive chemistry we have to do either with chemical compounds capable of taking regular geometric forms, to which we give the name of crystals, or else with liquids, such as alcohol and the oils already named.

There is, however, a form of matter derived from animal and vegetable sources which we have not yet been able to prepare, or in other words, there is a point beyond which at present we cannot go: I was about to say—a point beyond which we never shall go; but I will not say that, because it may savour of dogmatism, and this is a condition of mind which a man of science must do his best to avoid. So that although we cannot see at present the possibility of the artificial formation of the kind of matter to which I refer, I take it that he is a bold man who says that such artificial production is for ever impossible.

I will now show you some of this *organised* as opposed to *organic* material, the production of which by artificial means is now impossible. Here on the screen you have some of these curious forms, characteristic of life, with which chemists

have but little to do, and which I rather think they feel somewhat relieved to hand over to their brothers the biologists, who can tell us about their growth and their form, but who, if I am rightly informed, do not know much more about their real structure or their intimate nature than the chemists themselves. These round masses which you see on the screen are nothing else than grains of potato-starch. If you take a potato and grind it fine, and then wash away all the cellulose or fibrinous matter, you will have what is known as potato-starch left behind. It is a beautiful white powder, and if you take the least quantity of this potato-starch on the end of a pin, and bring it under the microscope, and examine it with a high power, this is what you will see. Now here we come to



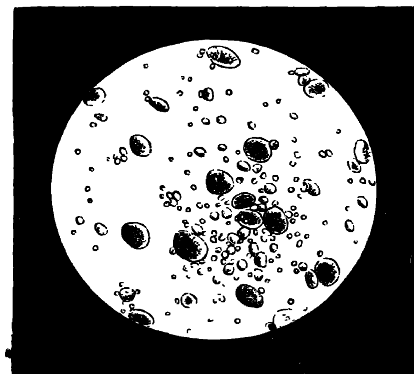
Fig. 15.

something totally different from anything we have had to do with before. Here we see something which has a peculiar structure, totally distinct from that exhibited in crystalline matter. These granules have a distinctly *organised* structure, and are of various sizes in different kinds of starch. Here is a picture of the grains of wheaten-starch. The diameter of the potato-starch granule is 0·185 mm., whilst that of the wheaten-starch granule is only 0·050 mm.

Similar organised globules or corpuscles are seen floating in the blood of all the higher animals, and these are produced by life alone.

And now, having thus brought you to the confines of the

vast subject of life and organisation, I must conclude with the hope that the short and imperfect reply which I have been able to give you to the question—What is the earth composed of?—will lead some of you to attempt to answer the question



more completely for yourselves, and thus induce you to begin in good earnest the study of nature, not only as being a never-ending source of delight, but also as the best possible means of clearing our minds from the cobwebs which too often obscure our thoughts and dim our recognition of the truth.

THE SUCCESSION OF LIFE ON THE EARTH.

THREE LECTURES

BY PROFESSOR W. C. WILLIAMSON, F.R.S.

LECTURE I.

WHEN this course of lectures was arranged, it was thought desirable that you should have brought before you, in a brief but connected series, a general idea of what may be called the Cosmos,—the universe; and accordingly, arrangements were made, that our friend Mr. Lockyer should tell you about the Heavens, that Dr. Roscoe should discourse to you of the Earth, and that I should follow suit, in giving you a sketch of the history of Life upon the Earth. This then is the task that has been imposed upon me.

If it be true, as many of our scientific friends believe, that man has had an ancient ancestry very different from that which we are now inclined to recognise, it becomes desirable that we should have some sort of idea, who and what those ancestors were. We are told that man was once not only a monkey, but that there was a time in which he existed as some yet more obscure form of the lower animal creation, and from which form he has developed to what he is now. This is the doctrine of the Evolutionists; a doctrine in which I need scarcely say there is a large amount of truth; a doctrine

that unquestionably explains much that has never been explained by any other hypothesis; but I have come to the conclusion, that though it does undoubtedly explain the origin of many of the lower as well as of the higher forms of animal life, I have never been able so to reconcile it with my knowledge of the facts as they stand, as to believe that it accounts equally well for the origin of man.

The study of the succession of animal life as it has appeared upon the earth is the study of an enormous number of isolated facts. Now isolated facts are always comparatively uninteresting. It is just in proportion as we can associate some general idea with those facts, and show that there exist points of union, links connecting them together, that they assume a new aspect, and exhibit a measure of interest they did not possess when standing alone. It is when thus viewed relatively to the doctrine of evolution, that facts concerning the origin and history of life appear to me to assume their newest and most independent interest And it is in reference to this doctrine that I shall endeavour to expound to you the leading truths of the science. The doctrine of evolution presupposes that external influences, acting through enormously long periods of time, have altered the character, the wants, and the organisation of living things. But such changes could not be produced quickly; our own experience of what has taken place during the historic age shows us that such changes must have been slow. The crocodiles, oxen, cats, ibisses, and various other creatures that were embalmed amongst the mummies of Egypt, were animals such as still live on the earth without having undergone any change; the species are still identically what they were in the age of the Pharaohs.

In like manner, when we glance at the Assyrian sculptures, we see that the negro at the time of the Assyrian kingdom was precisely what the negro of the valley of Sennaar is still.

Here then we have proof that, in the examples in question, external influences, acting through thousands of years, have failed to make any material impression upon objects that flourish around us. If this be true, and there is no question that it is so, it follows, that we can never hope to test the doctrine of evolution by experiment. Man's life is too short to enable him to obtain the necessary results. Where then must we look for evidence? I unhesitatingly say, that it can only be derived from the rocks of which the

crust of the earth is composed. It is impossible for us to assign definite periods to the ages of these rocks; we cannot say how many thousands or millions of years slipped by whilst those rocks were accumulating; but we know that those periods must have been enormous. I doubt not, that we should be much safer in counting them by millions rather than by thousands; and it is in the rocks thus slowly accumulated, that we shall obtain satisfactory evidence of what time can do in permanently modifying organic forms of life.

But unfortunately the records which the rocks give us are imperfect, and they are so for many reasons. These rocks have accumulated, generally speaking, under the sea, just as sediments are accumulating now. Most of our dry land was under the ocean at a comparatively late period. At a period geologically recent the Alps and the Apennines, the Andes and the Indian Himalayas, were all beneath the sea. A map of Europe pointing out what was land and what was water at a very recent date, gives you altogether different outlines from those you have at the present time. Such changes in the sea-level have been going on perpetually, and the areas over which sediments, brought together by oceanic currents, were accumulating, have consequently undergone similar changes. Nor have they ceased to do so even at the present hour. At every period there were large areas of land separated by oceans, —and at each one of those periods both the sea and the land had, in all probability, their respective inhabitants; but many objects must have been living on the land that never reached the ocean; and even of the few terrestrial things that were entombed in the sea, remembering at how few spots the geologist has opened the bowels of the earth, you will see that many chances exist against the probability of such rare relics being stumbled upon by the fossil-hunter.

Let me give you an illustration of what I mean. We have for some time past been dredging the ocean in all directions; expedition after expedition has gone forth, culminating in that noble and successful one of the *Challenger*. Through these agencies the deepest parts of the sea have yielded many sub-marine treasures, but has there been any one solitary instance, in the whole of these dredgings, in which a human bone has been fished up from the depths of the ocean? Not one; and yet we know that thousands of unhappy mariners are immersed for ever in that ocean each year of our existence. If then we merely trusted to what the dredge has brought up,

such results would tell us nothing of the life of man upon the earth. And so it must have been in all ages. It can only have been by fortunate combinations of circumstances that any particular deposit could give us a fair conception of what the life was, that existed upon the earth when that deposit was found.

If we examine the rocks composing what we call the crust of the globe, we discover a succession of layers arranged one upon another. The section on the screen may be taken to represent roughly a wide area, ranging from the central mountains of some continent to the sea, and such a section may approximately represent the structure of the outer portions of the earth's crust along a line hundreds, or even thousands, of miles in length. We here see that the lowest are the most ancient beds, and as we ascend from the lower to the upper strata, we arrive successively at those that are of more recent date. Of course if we merely dig into the earth at some few points, various parts of this series will be wanting; uplifted by volcanic and other causes, the rocks have frequently been tilted up on their edges, and since many of these uplifted portions have been swept away for thousands of vertical fathoms of thickness, by what we call denudation, it follows that many of the more modern rocks, though once existing at such spots, may have disappeared. We also find from observation that some of the more ancient rocks—as for instance those that form the mountain peaks of Snowdon and parts of Westmoreland—have not probably been entirely immersed under the sea for thousands, if not millions of years. And hence, while more recent deposits were accumulating in other parts even of the area now occupied by our own island, those particular parts may possibly never have been in such a position in relation to the sea as to enable them to receive a covering of the newer deposits. Thus you see, that, at many spots, we may fail to find the more modern strata, partly because they never accumulated at those spots, or after having accumulated they may have been swept away again by those vast denuding influences which have done so much to alter the physical structure of the surface of the globe. Nevertheless, if we begin on the south-eastern coast of England, and travel towards Snowdon, we shall cross the uplifted vertical sections or "outcrops" of most of the known rocks, beginning with the modern ones at the mouth of the Thames, passing successively the Chalk-hills of Hertfordshire, the Oolitic lime-

stones of Northampton, the Red sandstones and Coal-bearing strata of Stafford, until we finally reach the ancient slates of Snowdon and the Welsh borderland. Now you know very well that if a bricklayer begins to build a wall, he does not commence by hanging his top layer in mid air, and then building downwards; he puts his first layer of bricks on the solid ground, where he can obtain a good foundation, and then proceeds to build upwards upon this foundation.

And as a general rule we may safely affirm that this has been the case with the rocks of the section before you, as well as of this other one which shows the approximate relative thicknesses of the various layers that form the crust of the globe. At its base we have a series of strata only found in America—the Laurentian rocks, named from the river St. Laurence—near whose shores they are at least 30,000 feet in thickness. Above these is another series of American rocks, which possibly are also to be found in the Hebrides—these are the Huronian beds, probably 18,000 feet thick.

Then we come to some of our own Welsh and Westmoreland mountains, where we find the Cambrian strata, which add 15,000 feet more. Yet higher we have the Silurian and other Welsh and Westmoreland rocks, 32,000 feet thick. Others, known as the Devonian beds, still higher, are from 10,000 to 14,000 feet. It is unnecessary to follow the section to its top. Enough has been said to show what an enormous mass of rock we have to account for; and yet every particle of that mass has been slowly accumulated by agencies which, depositing atom after atom, continued their action through incalculable periods. When you observe how slowly such accumulations progress at the present time—and we have no other standard whereby we can judge of their rate of progress in past ages—we are driven to the conclusion that this pile of strata represents periods which the human mind can scarcely conceive of. During these periods, forces, which we call Forces of Nature, but which are merely the instruments of the Divine Architect of the world, have been in incessant operation, and it is to some of the results of that unceasing action, in connection with once living things, that we have to look to-night.

If it be true, as the doctrine of evolution requires us to believe, that animal and vegetable life began with some obscure germs, out of which, as ages rolled on, other and more complex objects were developed, and that in this way

plants and animals gradually increased in the complexity of their organisation as the world grew older, then, we should expect to find something corresponding with this order of development in the order in which plants and animals appear in the rocks. In the lecture of to-night, I hope to guide you in this direction, through what is called the Palæozoic age, the age in which many of the forms of life were very different from those now existing, but throughout much of which period certain types of organisation are found to prevail. Near the very bottom of the Laurentian series there has been found in Canada a very extraordinary object, a small magnified portion of a section of which is represented in Fig. 1. This is declared to be the oldest known fossil. There is some dispute as to whether it is a fossil, or a mere mineral

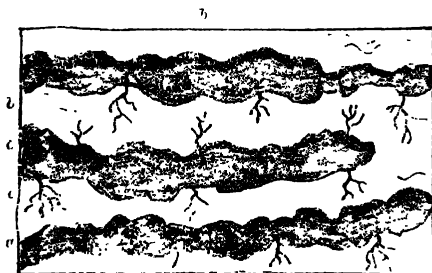


FIG 1.—Portion of a section of Eozoon canadense. (a) Cavities occupied by the living animal. (b) Calcareous layers secreted by the animal. (c) Branching canals in the calcareous layers.

organisation. It is called the *Eozoon*, which means the "dawn of life." Now that this is a fossil I have no doubt whatever; if so, it is the earliest trace we have yet met with of any animal form. We know that there are certain little objects now living in the sea called Foraminifera; objects that possess microscopic shells made out of lime which they extract from the sea-water; and as the animals perish, their dead shells sink through the ocean and accumulate in its depths, where they form vast deposits of calcareous mud. The valley of the Atlantic is largely filled with these deposits. Each of these microscopic objects lives an independent life; they are very minute—the largest recent Foraminifer I have seen scarcely equalling the size of half-a-crown; and living forms of this magnitude are very rare; generally speaking they are like

the dust that we see blowing about the roads on a dry summer's day. And yet, put them under the microscope, and you discover that they are really organic atoms which often display exquisite beauty. Now the probability is that the Eozoon was a creature allied to these Foraminifera, but instead of existing as a multitude of minute and separate protoplasms, as is the case with our living forms, in the Eozoon these protoplasms blended to form thin extended layers of jelly superimposed upon each other. As myriads of minute polype animals combine, at the present day, to form coral-reefs many miles in length, so the united protoplasms of the Eozoon constructed vast reefs of foraminiferous shell. Assuming these opinions to be correct, what position does this primitive creature occupy in the scale of organisation? It is as near the bottom of that scale as it well can be. The only objects with which we are acquainted that are lower, are certain microscopic, infusorial creatures, little specks of jelly-like protoplasm, that are found in both fresh and salt water, and of which it is absolutely impossible that any trace could be preserved in a fossil state. Thus far then the earliest known fossil creature presents itself in a form consistent with the idea of evolution. The rocks reveal no further indication of organic life until we ascend to the series called Cambrian, found amongst the mountains of Wales, Westmoreland, and elsewhere. This group of rocks was chiefly investigated by that noble-minded man, the late Professor Adam Sedgwick of Cambridge, whose ceaseless energy, bright intelligence. and manly character, long will cause his name to retain a foremost place in the annals of English science. At a comparatively low horizon of this Cambrian series there have been found at one or two localities, but especially at a place called Bray-Head near Dublin, the remarkable objects to which the name of Oldhamia has been given. These objects are found in such quantities that layer after layer of the rock is composed of them. That they are organic, and not mere mineralised forms, the result of crystallisation, is indisputable. We are not absolutely certain what they were, but we have every reason for supposing that they were Corallines, allied to those found so abundantly on our sea-coasts.

This second fossil naturally suggests the question, What is the position of the Corallines in the scale of nature? We have ascended to a considerable height in the series of rocks, and we should expect, according to the theory of evolution, to

have made some advance in the organisation of any fossils which those rocks may contain. There is no doubt that the Corrallines come next to the Protozoa, to which group the Eozoon belonged; they occupy a higher position, but it is still low compared with what is to follow. Thus far objects continue to be arranged in their right order. When we ascend still higher in this series we come upon an extraordinary set of forms of wonderful diversity. The oldest shell that we have found is a minute creature, differing from the ordinary shells with which you are familiar. It belongs to a group well known to the conchologist and geologist as Brachiopoda, and of which the best-known are called Terebratulæ and Lingulæ. These creatures occupy a position in the scale of organisation a little lower than such shell fish as oysters, cockles, and mussels. It is to this somewhat lower group that the Obolella—the first form of shell-fish that has been found amongst the Welsh mountains—belongs. I do not mean to say that this is the oldest shell that ever lived; I merely say that it is the oldest of which we have found any trace. A little higher up we come upon a remarkable outburst of life; we arrive at a part of the Cambrian series in which we find a number of extraordinary creatures, called Trilobites. They are "crustaceous" creatures, allied to crabs and lobsters, but occupying a lower position in the crustacean series than crabs and lobsters do. Associated with these, we find fossil sponges, somewhat similar to those you are familiar with at the present day. These well-known objects began to make their appearance upon the earth even at this early period. Associated with these sponges and curious crustaceans, we also come upon objects known as Encrinites, representatives of which are still living in our seas. These are animals very closely allied to star-fishes, but which, instead of being free and able to wander hither and thither, are planted upon a fixed stalk. The stem does not afford nourishment to the star-fish at its top, but the star-fish affords nourishment to the stem; and although it has certain root-like organs, these do nothing for the creature beyond fastening it in the sand, in which it chiefly resides. They do not draw any nourishment from that sand as the roots of a tree would do; they merely fix the creature there. The mouth, which is in the middle of a terminal series of branching arms, receives the food that those arms entangle; and it is this part of the creature—the star-fish part—that nourishes the stem and roots, and not the stem and

roots that nourish the fish. These Encrinites now begin to be comparatively abundant; we shall find them still more as we ascend higher. Thus we see that we have already made a somewhat important advance in the development of animal life. Ascending still higher, we reach the Silurian group of rocks, for the investigation of which we are chiefly indebted to the labours of Sir Roderick Murchison. We were long

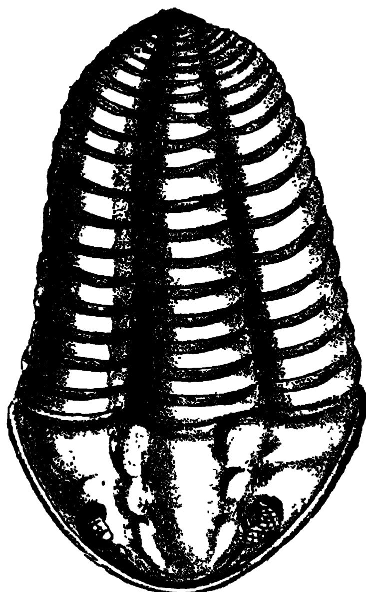


FIG. 2.—Upper surface of a Trilobite from the Silurian rocks.

familiar with the fact that, running down the border-land between England and Wales, there was a long line of fossiliferous limestones, of which little was known; they were only recognised by the vague name of Transition limestones. We merely knew that they were thought to be somewhat more modern than the older slate rocks, and somewhat older than the coal-beds of the neighbourhood of Manchester. But Murchison found that these rocks were as capable of being studied and arranged in chronological order as any other rocks with which we are acquainted, and the publication of

his great book, entitled *The Silurian System*, gave us the clue wanted to the understanding of the entire series. It turned out that this Silurian series of strata, which had been so long neglected, was not only richly fossiliferous, but was quite as much so as any rocks seen in other portions of the fossiliferous series. On entering this new region we still find that most of the types met with in the Cambrian beds lived into the Silurian age, though the species were different; we still have the Sponges and Encrinites. The Trilobites still occur, and sometimes in extraordinary profusion; in fact this Silurian age was the one in which they culminated; being more abundant then than at any period before or after. In the Arctic seas at the present day there are certain small creatures so abundant that when a whale opens its jaws and takes in a mouthful of water, after squirting the water out between the plates of whalebone, which serve as teeth, it retains a huge mouthful of these small objects. There must have been something like this in the ancient Silurian seas, because two of these Trilobites, the Trinucleus and the *Asaphus Buchii*, occur in such numbers, that entire strata largely consist of their remains. We now come upon certain things that we have not hitherto seen. We find, for instance, a group of extraordinary objects, called Graptolites. For a long time we doubted what these were, but they are now understood to be a remarkable group of Corallines. They were not found in the Cambrian beds, nor have we found them at a later period than the Silurian. I may refer here, whilst speaking of these Graptolites, to the great discovery which first erected geology into a science, and which was made by the veteran friend and tutor of my younger days—I mean the late father of English geology, William Smith. Previous to Smith's day the rocks were unclassified, because we had no means of estimating accurately their relative ages. Smith however discovered that in all this pile of strata—at all events in such portions of it as he was familiar with—each stratum or group of rocks possessed organic remains that were characteristic of that group, and that were not to be found in any other. Consequently, just as when you disinter some accumulation of buried antiquities, you see by the stamp upon the coins whether they belonged to Greek, Roman, or mediæval times, so the geologist, taught by Smith, learned to recognise, not, it is true, the actual age, but the relative age of the rock which he happened to be inspecting, by means of what my old friend

Dr. Mantell termed the "medals of creation." By this he meant the peculiar fossils which that rock enclosed within its stony matrix.

In strict accordance with Smith's theory, when we find these Graptolites we have every reason to believe we are dealing with Silurian rocks. In these rocks we also come across star-fishes. Thus you see we are steadily advancing into the midst of things with which we are still familiar in a living state. When we reach the middle and upper part of this class of rocks we find Corals extremely abundant; we find remains of Corals even among the Cambrian beds; but when we reach certain deposits in the middle and upper part of the Silurian system, we have the clearest evidence of the existence of tropical seas, because Corals like those that now flourish only within thirty degrees of the equator, have been as abundant as they now are in tropical regions. The limestone beds of Dudley, in the iron district, are almost entirely made up, in some places, of vast accumulations of tropical Corals. But besides these, we also find that there has been a rapid development in molluscan life during the Silurian age; and not only so, but we find here a remarkable development of that highest type of molluscan life known by the name of cuttle-fishes. I do not mean to say that we have actually found the cuttle fishes themselves, but we have found shells which we know must have been embedded in the soft tissues of cuttle-fishes. When I tell you that some of these shells must have been seven or eight feet in length, you may judge what must have been the size of the living cuttle-fishes to which they belonged. Now mark what this means. Recollect how comparatively low our position still is in the scale of stratified rocks, and remember that these cuttle-fishes not only occupy the highest position in the scale of molluscan life—that is, the life of shell-fish—but that in many instances they approximate so near, in some parts of their organisation, to the vertebrate section of the animal kingdom, as almost to constitute a connecting link between the one and the other. For instance, the cuttle-fish has a brain enclosed in a cartilaginous cranium, a brain-pan made of gristle. Now here we clearly have an approach to the skull of the vertebrate type of animals. Still further; the cuttle fish has special ganglia, or masses of brain, set apart for the exclusive purpose of giving origin to the nerves of sight. This is precisely what occurs in our own bodies. The nerves of sight in the human body

arise from two special nervous ganglia, the "optic ganglia"; and we find two perfectly distinct ganglia, one on each side of the brain of the cuttle-fish, from which its nerves of vision proceed. Thus we see that, in more respects than one, these cuttle-fishes and their innumerable allies, not only occupy a high position in the scale of molluscan life, but they almost form a stepping-stone across the boundary which connects the molluscs with the vertebrate animals. In the Silurian age not only were these cuttle fishes represented by the Orthoceras, but we find other external chambered shells of the same general type corresponding to the living Nautilus.

But we must advance yet a step higher. There have been found in the uppermost parts of this Silurian series of deposits the remains of fishes which are met with here for the first time. One of these fishes, the Cephalaspis, so much resembles a large Trilobite in form that, when first found, we need not be surprised at its having been mistaken for one. Further investigation, however, showed very clearly that it was a true fish. It might readily have been supposed that the Cephalaspis was a crustacean in course of development into a fish; but the peculiar shape which suggests this idea is only one of those outward resemblances, devoid of real identities, that are apt to mislead imaginative minds. When we examine the organisation of this object, we find that it had genuine bones like other fishes, and that its hard structures were altogether distinct from the peculiar integument that constituted the protecting covering of the crustaceans.

But associated with this Cephalaspis there also existed in the later Silurian days another fish. And now comes one of the perplexing facts which geological investigation has brought to light, and which appear unfavourable to the doctrines of development and evolution Murchison first showed that in the upper Silurian beds there existed the remains of species of shark, and other observers have verified the statement. When we inquire what position the sharks occupy in the scale of fish-organisation, we learn that they occupy its summit. They possess at the present day a brain organisation which brings them extremely near to the reptiles. There is every reason to suppose that the particular fossil found in these Silurian beds is not only a shark, but that he belonged to one of the highest types of the sharks. We have here a seriously awkward fact. Nature has apparently taken a step forwards, in advance of her time. Between these sharks and the lowest forms of fishes

there exists a vast series of fishes such as we see in our markets, but which have apparently no representatives in this ancient epoch. In the first place, if you take a salmon or a cod-fish you will see that its vertical tail divides into two nearly equal lobes; and if you trace its long vertebral column or backbone, you will see that it terminates midway between the upper and the lower lobes of the tail; but no such fish is to be found in any of these more ancient rocks. Before we can find fish like the recent ones, so far as the tail is concerned, we must reach the Oolitic period. Up to this point of time all the fishes that we find are either sharks, or belong to another great group, the Ganoids, of which I shall have to say a word or two presently. Here, then, I repeat, we have a difficulty. We cannot bridge over the gap which connects these sharks with the lower forms of animal life which I have been endeavouring to describe. What future research may do to remove this stumbling-block we cannot tell—but at present it does stand as a serious hindrance to our unreserved acceptance of the evolutionary theory.

But we must now pass another of the boundary lines dividing separate groups of strata, when we shall reach the Devonian beds; these are a very remarkable series of rocks, the relations of which have only become intelligible to us of late years; but they will have a special interest for some of you, if, as is probable, I have some Scotchmen amongst my audience. It was from amongst this series of Devonian beds that one of the brightest intellects of Scotland fought his way up from wielding a stonemason's hammer to becoming editor of one of the ablest of the Scotch newspapers, and the author of some of the most eloquent descriptive books ever written by mortal pen—I mean the late Hugh Miller. Now Miller, and others who followed in his footsteps, brought to light from this Devonian series of rocks a very remarkable set of fossils. I won't dwell upon the shells and other curious objects found in these rocks, for time is short, but I will call your attention to some of the fishes with which he first made us acquainted. One of these is the Pterichthys, an extraordinary-looking fellow, with two wing-like appendages hanging by his side, and covered with an armour of large angular plates that remind us more of a tortoise than a fish. The Coccosteus is another, and if possible still more curious fish, with a tadpole-like head, resembling in shape those black and slimy froglets and newtlets that dabble at the margins of our ponds in early spring. But besides these examples we have other modifications

of the Ganoid fishes, in which rhomboidal scales overlap each other like the slates of a house, and in which the vertebræ of the tail run very conspicuously into the upper lobe.

The group to which all these fishes belong is not yet quite extinct. It continues to be represented by the bony pike of North America, and a similar fish, called the Polypterus,

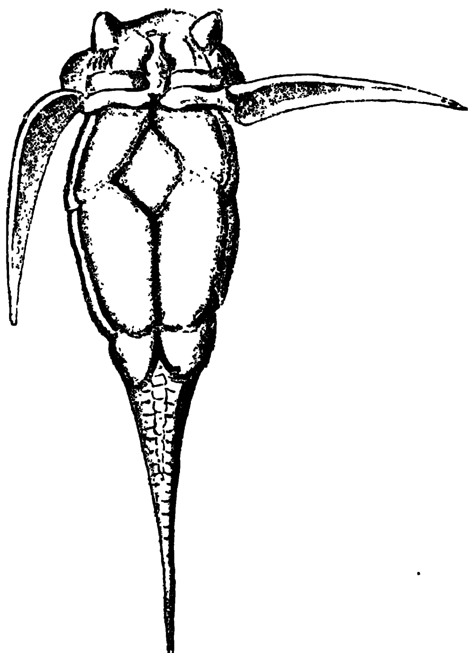


FIG. 3.—Under surface of a Pterichthys from the Devonian rocks.

is found in the Nile and in other rivers of Africa. In addition to the scales of these fishes differing from those of the cod and salmon in outward form, they are also much more bony in their internal structure. Ascending through the whole of this pile of ancient rocks, we discover no kind of fish excepting members of the shark tribe, including their relatives the skates, and these Ganoid fishes, until we reach the Chalk strata.

We still find in this Devonian bed the Cephalaspis, which continued to linger through the earlier parts of the Devonian age. But, before we leave this age I must introduce to you another acquaintance whom I have previously neglected but whose race began its career during the epoch of the upper Silurians which we have already considered. He is called the Eurypterus, and is a sort of half-developed lobster. He grew to the stature of an adult, whilst he retained some of the organisation of his earlier life. He seems as if his limbs had forgotten to grow along with his body. But when I tell you that he was often six or seven feet long, you will see that he would afford an excellent dinner to one of the lobster-loving sharks of that ancient date. He disappeared entirely at the close of the Devonian age, and there has been nothing like him since. I suppose the sharks of that period ate him up, and there was an end of him. "We shall not look upon his like again."

Thus far I have made no allusion to the vegetation existing on the earth. We find vague traces of plant-life in the Silurian and Cambrian beds, but, so far as we can ascertain, those plant-remains are merely fragments of seaweeds; we have no very definite evidence of anything higher than seaweeds existing in those older days. For a long time we were equally unaware that any higher flora lived in the Devonian age; but my friend Dr. Dawson, of Canada, has, within the last few years, revealed to us the existence of magnificent forests during this geological period. This flora corresponds very minutely in all its general features with that seen in the coal-beds surrounding Manchester.

For instance, we find in it extraordinary Calamites, huge plants allied to the horsetails of the present day. Then it contained Lepidodendra, gigantic representative of the dwarfed, living club mosses, but instead of creeping along the ground, and barely lifting their heads twelve inches from the soil, these were magnificent trees, rising 100 feet into the air. Then we also had a rich array of ferns. We must not overlook the notable fact that in these Devonian beds this wonderful flora bursts upon us with almost the suddenness of a flash of lightning. Most of its plants are what botanists call cryptogamic; that is, plants that have no flowers, but merely develop what are termed spores, and not true seeds. But side by side with them we find a wonderful display of coniferous plants, allied to the tribe of pines and firs, and which we know to be flowering and seed bearing plants; but

they are flowering plants of a very peculiar type. Whether we may consider them as having a higher or lower organisation than oaks or elms, is a point on which opinions differ; but our best botanists incline to regard them as connecting the cryptogamic Lycopods on the one hand, with the flowering trees on the other. There exists no evidence showing that any of our ordinary forest-trees grew on the earth in this Palæozoic age. Up to the close of this vast period the flora was confined apparently to these cryptogamic plants and conifers. We must



Fig. 4.—Pinnule of a Fern from the coal-measures.

not overlook the notable fact that this wonderful flora bursts suddenly upon us. We have yet found no indications of a previous and less highly-organised flora, out of which that under consideration might have been directly developed, at the same time it is possible that some such may have existed. without any traces of it having been preserved in the older rocks.

We must now leave the Devonian age, and come to the

Carboniferous beds, that is, to the group of strata to which our British coal-measures belong. These, of course, are beds that interest us in every sense of the word, and were I to deal fully with them it would take an hour, even to clear the ground. I need scarcely say that the Carboniferous age has left rich blessings to mankind. Though it is not the only geological period which has supplied the world with that invaluable article of fuel which we call "coal," it is undoubtedly *the* period in which the finest and most widely diffused beds of coal were accumulated, and consequently our manufacturing interests owe more to this than to any other series of deposits. Not only is it our chief source of coal, but it is also that from which we draw our most valuable supplies of iron. So that here we get, side by side, the raw materials for the construction of our machinery, and the fuel by which that machinery is to be worked. At the time when the coal-measures began to accumulate our country exhibited very different outlines of land and sea from what it does now. If we go to the lowest of these Carboniferous strata in Western Yorkshire and Derbyshire, we there find the rocks in the shape of grey limestones—the Derbyshire limestone, with which most of you are familiar, and of which you make use in building your garden-rockeries; on visiting Derbyshire you see these limestones, rising on all sides, constituting the vertical cliffs that add such a charm to Derbyshire scenery. The fossils which they contain show that these limestones have been accumulated in a deep sea, which covered Derbyshire and the adjoining parts of Yorkshire. But when we cross over into Fifeshire and the neighbourhood of Edinburgh, we find that these thick strata of marine limestones are altogether absent. Whilst Derbyshire was deep under the ocean, there flourished in North Britain magnificent forests, analogous to those I have been describing as existing in the Devonian age By and by, however, in our midland part of the country, the sea gradually became filled up with its accumulating organic sediments, in addition to which it is probable that the land itself slowly rose, and after passing through a transition period, in which sea seemed to struggle with land for the mastery, we arrive at what we call the Mountain coal mines. These are a series of very thin coals, which run along the hill-sides of Halifax and Oldham, and one of which, cuts horizontally through the top of Rivington Pike. Every bed of this coal represents the beginnings of an ancient forest. As

yet the forests of this district evidently had not attained to any prolonged duration, as is indicated by the thinness of the coal seams; but when we rise a little higher we come to the rich coal-mines round Wigan, such as the Arley mine and others, with beds of coal from five to seven feet thick, and which have been entirely produced by the decay of the leaves, branches, and prostrated trunks of the forest-trees which accumulated on the ground where the coal beds now exist.

We have now reached dry land and forest life. There is evidence amongst these beds that not only did plants grow, but that land-shells flourished under their shade; two land-shells having been found in coal-beds of this age in Canada. One is a true snail-shell, and the other is a Pupa—a genus of

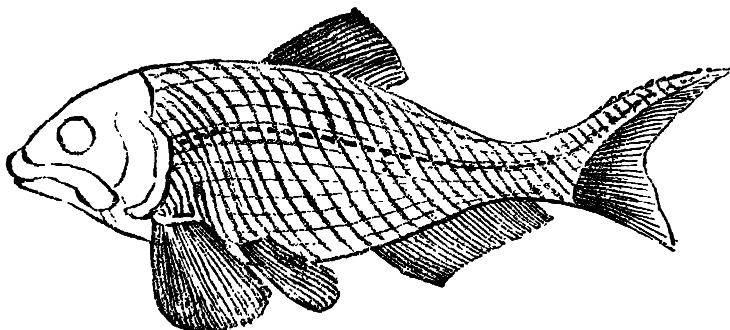


FIG. 5.—A Ganoid fish from the coal measures with the "heterocercal" tail, *i.e.*, having the vertebral column prolonged into its upper lobe.

molluscs allied to the snails still found living in our own woods. If you were to examine the trees growing in the damper parts of Bowdon Woods I have no doubt whatever that you would find shells of the same kind adhering to their bark. We have also clear evidence that insects abounded at this period. Spiders, too, were not wanting, spiders of large size having been found in some of the ironstones of this Carboniferous age. Numerous shark-like fishes were associated with equally numerous Ganoid ones in the deeper waters, all these fishes having the "heterocercal" tail of Fig. 5, which represents a Ganoid from the coal-measures. In the marshes and estuaries there existed numerous Batrachians, or reptiles allied to the frog and newt; but some of which must

have been almost as large as crocodiles. Combining all these facts, we find that so far as animal life is concerned we are steadily rising in the scale of organisation, and approaching nearer to living types; but so far as vegetable life is concerned, we are still in the same position as we occupied in the Devonian age. We find now that amongst the trees there still are gigantic horsetails, relatives of those which you see in our ditches and ponds at the present time; the latter plants are generally not more than a foot or eighteen inches high, though occasionally reaching to four or five feet: of which size I have found them in the damp parts of Derbyshire. But what size were these fossil "Calamites"? I have specimens of these ancient horsetails in my cabinet that must have been twenty or thirty feet high, and with stems nearly as thick as my waist. Then we have the plants already referred to as allied to our club-mosses. I mean the Lepidodendra and Sigillariæ, and we find that they often rose to 100 feet in height. We have in the Owens College museum a carefully-made cast of one of these huge stems, discovered at Dixon Fold, on the Manchester and Bolton Railway, and which measures twelve feet in circumference near its base. How very peculiar must have been the aspect of forests composed of such gigantic cryptogams!

There was also an undergrowth of ferns and smaller horsetails, with here and there a few Tree ferns vainly aspiring to rival the aristocratic Lycopods that towered above their heads, and on the drier uplands the pine-forests appear to have flourished apart from their cryptogamic neighbours. There is evidence that the climate of that Carboniferous age was not that of our temperate region. We have reason to suppose that it was a warm one, but we have no proof that it was tropical in its character. Whatever it was, it was the same in Greenland, in Central Europe, and in Australia, since in all these remote localities we discover similar fossil plants in the Carboniferous beds. There must have been a peculiarity in the physiognomy of these Carboniferous forests. No flowering plants gave local colour to the landscape. There were no grassy meadows covered with daisies and buttercups, or rich moorlands glowing with the purple and gold of heather and furze. The entire aspect of the vegetable world must at that time have been something like what Mr. Wallace tells us is so characteristic of tropical forests in the present day, where we see every shade of green. The earth is ladened with the

luxuriant vegetation which it supports, but you have no masses of flowers giving distinctive colouring to the landscape. You have, it is true, individual trees that are rich in their gorgeous bloom, but they are isolated and lost in the verdant expanse. Such also must have been the hue of the woodlands which flourished in the Carboniferous age.

As we ascend through the Carboniferous rocks we find that marine objects become gradually fewer in number. In the older beds a great many of the types of shells that characterise the Silurian and Devonian ages still flourish. We find Corals and Encrinites; we also discover a few small Trilobites which still linger, but which now take their departure and we see them no more; but as they disappear we have evidence that their place is being taken by the living Crustaceans that may be regarded as the nearest relatives of these Trilobites—I mean the curious Limuli, or king-crabs, now found in the tropical parts of the world. The king-crab, which exists in the seas of many tropical regions, is very like the Trilobite in its structure and general appearance; and the advocates of evolution would contend that the king-crab was evolved from the Trilobite. Be this as it may, I can only say that we have the last descendants of the expiring Trilobites preserved in the Carboniferous rocks, and, side by side with them, we have the Limuli beginning their race of life. The former are the latest of all known Trilobites, whilst the latter are the earliest of all known king-crabs; but there is not the slightest indication of any transmutation of the one into the other of these two fossils. Of course it is not impossible that there may have been embryonic links establishing a transition from the Trilobite to the Limulus, but geology gives no evidence whatever of the existence of such links. The Limuli are very definite in their shapes, and cannot by any stretch of the imagination be made to merge into the little worn-out Trilobite that was evidently coming to the end of its days.

Above these Carboniferous rocks we have a group called the Permian beds, upon which I will not dwell long. If you go to the neighbourhood of Collyhurst, near Manchester, you will probably still find traces of an old quarry, called the Vauxhall quarry. That quarry was well known thirty years ago, because it was from it that the Manchester iron founders of that period obtained sand for constructing moulds in which to make their iron castings. Now that sandstone rests upon

the coal strata, and forms the base of this Permian series of rocks. Then there were found, not far from Vauxhall, a few thin layers of limestone; and in the neighbourhood of Bedford, near Worsley, these limestones are a little more fully developed. These limestone rocks contained peculiar fossil shells characteristic of the Magnesian limestone, which is a member of the Permian series.

On going eastward across the Lancashire hills we come to a series of beds of yellow limestone, which you will see in cuttings in the neighbourhood of Wakefield and Normanton; these again are the same Magnesian limestones as those thinner ones found in Lancashire. When we reach Durham we find this same limestone still further developed, attaining, in that district, a thickness of something like 500 feet. It is obvious that the sea in which these limestones were deposited was a shallow one in western Lancashire, and deepened as we approach the Durham coast. This Magnesian limestone—so called because it contains a small percentage of Magnesia mixed with calcareous matter—is rich in fossil remains. Many of these remains are peculiar. They are fossils that we have not found in the Carboniferous beds below, or in the Triassic beds above; some of these Permian beds are often exceedingly rich in the remains of Ganoid fishes; but though the species are distinct, the types are similar to some found in the Carboniferous strata. . . . The chief importance of these beds to us now is found in the circumstance, that in the neighbourhood of Bristol the remains of reptiles of a higher order than any we have hitherto met with have been found in them. These reptiles are partly allied to the lizards, and partly to the crocodiles.

Thus we see that so far as we have accomplished our ascent from the lowest to the highest strata, race has been supplanted by race, generation has followed generation; occasionally we have seen evidence that seemed to indicate the existence of links connecting a departing race with another that succeeded it; suggesting the possibility of a gradual transition having taken place from lower to higher forms as years rolled by. There are also broad general indications of an upward progress, shown by the introduction, from age to age, of animals having a higher organisation than those which preceded them. But notwithstanding this we are obliged to admit, that when viewed in minute detail, the rocks which we have examined give but a very limited support to the doctrine of evolution.

I will not dwell upon this subject now, because I shall have to give you a slight *résumé* of the matter in the concluding lecture of the series. I have thus far guided you only through the Palæozoic series of rocks; and that but hastily and imperfectly, because of the limited time at our disposal. I have only been able to give you a bird's-eye view of the country over which we have been travelling; trusting that you will again go over the ground by yourselves, and in a more detailed and leisurely manner.

THE SUCCESSION OF LIFE ON THE EARTH.

LECTURE II.

In my last lecture I conducted you through what is called the Palæozoic period of geology. You will recollect I pointed out to you, in that lecture, that geologists roughly divided the time, during which the earth has been undergoing geological transformations, into three great ages: the Palæozoic, or ancient age; the Mesozoic, or middle age; and the Cainozoic, or recent age.

The Palæozoic age, which we dealt with last Tuesday, is characterised equally, as we saw, by the creatures which lived in it and by the creatures which did not then exist. We found that there were special types of living things which flourished, more or less, throughout even the later portions of that age. But we now cross a boundary line, beyond which we find evidence of a great change. I do not mean to say that all the genera we shall meet with are wholly new, because such is not the case. On the contrary, there are large numbers of types and patterns that appeared upon the earth in the earliest portions of its history, which never passed away again, and which are living at the present time; but, whilst this is perfectly true, it is equally so that, at the boundary line we are now crossing, like passing from one hemisphere to another, we leave behind many things that we have become familiar with, and are brought face to face with new forms of organic life. The boundary line of which I now speak comes high up in the scale of rocks. Judging from the immense pile of strata through which we have already ascended, you might suppose that we were arriving near the end of our journey. But this is very far from being the case. You will learn, as we proceed, that, though the thickness of the remaining strata is insignificant, the interest of their organic contents, and the vast changes which those organisms have undergone, becomes increasingly remarkable. There seems to

have been a marvellous quickening in the power of developing life as the world grew older. During the earlier stages of the vast Palæozoic age, the progressive development that took place advanced much more slowly than it did towards its close—and we shall find that after entering upon the Mesozoic period, the rapidity with which that development increased becomes more and more marked as time advances.

Leaving the Palæozoic rocks, we come to the base of the Mesozoic series, represented by what are called the Triassic formations. These are strata with some of which you have the opportunity of becoming sufficiently familiar, because the most conspicuous of them is that red sandstone which you see extending in so many directions around Manchester, but especially throughout the whole plain of Cheshire. The red sandstone, and the marls that surmount it, are especially rich in the rock-salt which is extracted from the salt-mines of Northwich and various other parts of Cheshire. But it is not with the physical and inorganic features of this age that we have now to do.

At the same time I must just mention that there exists in the middle of this series of Triassic rocks in Germany a comparatively thin limestone-bed that is rich in fossil shells. The occurrence of this "Muschelkalk" is rather important to us, since we happen to have in Britain no representative of this stratum, and, but for its existence elsewhere, we should have been very ignorant of much of the life of the Triassic age. The Triassic rocks seen in England are extremely barren of fossils. At the same time they do afford us some information which we shall find to be significant. In the first place, the Muschelkalk tells us that the family of Encrinites is still represented; all the types of this group which are found so abundant in the Palæozoic beds have disappeared; every one of those numerous species have become extinct. In their place, in this German Muschelkalk, which, translated into plain English, merely means "shelly limestone," we find a new Encrinite, a true member of the Crinoidal family and yet altogether different from those whose place it has taken. The question inevitably arises, "How and whence has this new Encrinite come?" It is very distinct from those of the Carboniferous rocks; merely preserving the general plan and pattern according to which they are all constructed; we cannot so connect it with any of the extinct forms as to suggest a probability that it has descended directly from them; it

is the isolated known representative of the vast race whose place it has taken so far as the Triassic strata are concerned.

Then there are shells peculiar to this age, but I need not dwell upon them. Most of them are merely useful to the geologist in helping him to identify the particular rock that he may happen to be examining. But the case is different when we turn our attention to some extraordinary creatures which, in all probability, once roamed over the very spot where you are now sitting. The history of these creatures is decidedly peculiar. In the first instance there were found, at Corncockle Muir, in Scotland, some slabs of sandstone, the surfaces of which exhibited impressions of what were evidently the footsteps of four-footed creatures. These impressions were generally found on marls that were covered over with a bed of sandstone. The impressions in the clay were hollow, and of course the sandstones that filled up these hollow impressions were in relief. It very soon became clear that, whatever the creatures were to which these marls owed their existence, they had been living things that had walked upon a half-sandy, half-muddy tidal shore, and had left their footsteps as they travelled along, which footsteps had become hardened by the sun before the returning tide was able to wash them away. These impressions afterwards became covered with layers of sand, which protected their sharp outlines from injury, until they were once more brought into daylight by the labours of the quarryman. We have strong reasons for concluding that these footsteps were formed on a tidal shore, and the evidence that leads us so to conclude is of a kind that is perfectly available to every Manchester man. As you walk through the streets of Manchester you may have noticed the difference between the flags of our pavements and those you find in the towns of western Yorkshire; for whilst those of Yorkshire are almost as smooth as the platform upon which I stand, those of Lancashire are rough, often marked with irregular, wavy ridges and furrows, not altogether comfortable to walk upon. Now what do these ridges and furrows mean? You can easily answer this question for yourselves if you recall the similar irregularities constantly left by the retiring tide on the sands of Southport and Blackpool. When tidal waves are moving slowly over a layer of mud or sand, some remarkable movement of the water, that is not clearly intelligible, produces these ridges and furrows. The sandstone from which we have obtained these fossil footsteps often exhibits ridges and furrows

exactly similar to those recent ones to which I have called your attention; and as we never see them excepting where there has been flowing water, and especially tidal water, we come to the conclusion that the sands on which these footsteps were impressed were covered periodically by the tidal wave.

The next question is, by what sort of being were these footsteps made? We must go to different parts of the world for a full response to this query. These footsteps have been found very abundantly in our own Cheshire district; magnificent examples of them occur near the village of Lymm, and another remarkably fine set of them was discovered at the Stourton quarries, near Liverpool. Examining these footsteps more minutely, we see, in the first place, that there are two sets of them; there is one series of very large impressions produced by a large foot; and alternating with these is a corresponding series of much smaller ones. Since these impressions very much resemble those which would be made by pressing the outspread palm of the hand upon soft, wet sand, before any remains of the creature which made them had been found the latter was called the Cheirotherium, or beast with a hand. From the regular alternation of large impressions with small ones it was clear that the fore and hind feet of the creature had varied greatly in their dimensions; and further examination led to the conclusion that the smaller feet had belonged to the fore limbs and the larger feet to the hind ones. The probability that this was the case led naturalists to conclude that the animal had been a huge Batrachian, a near relative of the frogs and newts. In time a few of its bones and teeth were discovered; and so far as they went, they gave support to the above conclusions. After this, still more perfect examples were obtained, which leave no doubt that geologists were correct in the opinions they had formed respecting the nature of the Cheirotherium. But before this identity of the foot-prints and the fossil bones was established, the name of Labyrinthodon had been given to the latter by Professor Owen, owing to a remarkable labyrinthine pattern exhibited by transverse sections of the teeth, peculiarities which he described and figured in one of his works. This creature was one of the most remarkable animals living in the age of which I am speaking. Not that it appears here for the first time; later researches have shown that similar animals lived amongst the marshy forests of the Carboniferous

age. Not only have magnificent skulls of this creature been found in the coal-beds near Glasgow and other places, but impressions of his footsteps have been found, similar to those belonging to the Triassic period. Owen's name of Labyrinthodon is now generally identified with this strange creature, in which science, art, and commerce, meet very strangely together. When Owen obtained the first of its teeth, he found in transverse sections of it the labyrinthine structure, to his figure of which I have already called your attention; very shortly after that drawing was published it reappeared in Manchester, forming the centre of a printed pocket-handkerchief!

Even in England the footsteps of several other reptiles appear along with those of the Labyrinthodon. Some of these footsteps look much like those of tortoises, but whether this is really the case or no, we are not sure. In some limestone beds near Bristol there have been found the bones of some reptiles of unquestionably higher organisation than Batrachians, whilst at Elgin, in Scotland, besides a small lizard like animal, the remains of a huge crocodilian creature have been disinterred from beds which are now generally admitted to be of the Triassic age.

However remarkable the footsteps of our British reptiles may be, they are insignificant compared with what occur abundantly in the United States. Such footsteps have been found there in immense numbers, and of at least twelve species of lizards, tortoises, or turtles, and Batrachians. But here another type of footstep abounds—viz. those of at least thirty-two species of three-toed bipeds, believed to be those of birds like the ostrich—but some of which must have been four times as large as the living ostrich, and yet of the actual remains of all these numerous creatures no fragment has yet been discovered in the sandstones of Connecticut.

Turning to the Triassic plants, we discover that the old Coniferous species of the coal-measures are gone, and are replaced by other forms, such as the genus *Voltzia*, which is altogether new. We do, however, find in these Triassic beds some representatives of the Calamites, or ancient horsetails, which are so common in the coal-measures, but they are feeble representatives of their ancestors. As these ancient horsetails disappear, their place is taken by the true modern horsetails, which we find for the first time in the newer Triassic rocks of the neighbourhood of Strasburg and elsewhere. We call this

fossil genus Equisetites, to distinguish it from the living Equisetums; but I have no doubt, both from the organisation of its stem and the peculiarities of its organs of fructification, that it is a true horsetail, differing chiefly from the living ones in the large size to which it attains; instead of the diminutive plant we now find in our marshes, it grew to a height of twenty or thirty feet. Interested in the origin of this Equisetites, I made a journey to Strasburg to examine the specimens in Professor Schimper's well-known Strasburg museum. I wanted to see if I could detect anything in the Triassic Calamites, found in that district, that would show a transition from the Calamitian type of the coal-measures to this Equisetaceous type; but I could not find the least indication of transition from the one to the other. The characteristics of each of these two appeared to me perfectly definite, and not in the least to merge into each other. Whether any transitional form ever will be discovered, uniting the ancient to the modern forms, remains to be seen; but at present geology reveals no such transition. The old race, which we found to be most abundant and widely prevalent through the age of coal, as well as through the Devonian period, now dies out under the influence of agencies unfavourable to its continued life, and a new one takes its place, coming we know not how or whence.

We further find in these Triassic beds traces of a group of semi-tropical plants called Cycadeæ, which do not occur in these temperate regions, but which abound just outside the tropical zones of both the Old and New Worlds, where the tree-ferns, india-rubber plants, and pepper-trees flourish. Recent investigations have made it more than probable that some of these plants flourished in the Carboniferous age.

But I must now cross another of the boundary lines which separate one age from another. We pass from the Triassic to the Oolitic strata. At this point of transition we meet with some new phenomena. In the first place, there have been found in two or three parts of Europe—including our own country—some fossil teeth of a true mammalian quadruped, and found so near our last boundary line, that opinions have differed as to whether the fossils belong to the Oolitic rocks above or to the Triassic rocks below. We have hitherto seen no representative of this division of the animal kingdom. Hence, so far as we now know, this "Microlestes," as the creature to which these teeth belonged is called, is the oldest of known mammalia.

It is somewhat dangerous to attempt to reason from a few solitary teeth as to the nature of the animal to which they may have belonged; but the probability is that it was either a Marsupial creature, that is a creature somewhat allied to the Opposums of America and Australia, or if not that, to some animal of a closely-allied type. I shall have to refer again to the question of Oolitic mammals as we proceed; I merely mention it now because of the position in which these remains were found. For some time after the discovery of this animal it was generally regarded as an Oolitic fossil, but later investigations indicate that it really belongs to the upper part of the Trias; be that as it may, it constitutes the first known example of that profuse mammalian life that is now so abundant on the earth.

Before actually crossing our new boundary, I must call your attention to a most extraordinary and anomalous state of things existing at two localities in South-eastern Europe. I have told you that throughout the world many of the Palæozoic types of life disappeared even before the close of the Triassic age; but at Hallstadt and St. Cassian, the Palæozoic and Mesozoic ages seem to have overlapped in a most exceptional manner. We have found nothing like it in rocks of this age in any other part of the globe. At these spots we find many of the Silurian and Carboniferous types, which we thought had disappeared altogether, intermingled with some of the most characteristic fossils of the Oolitic strata—a combination which is altogether of an exceptional character.

These Oolitic rocks are so designated because they contain a large number of limestones made up of little rounded granules, which resemble the eggs, or what you commonly call the roe, of fish. So close is this resemblance, that you might imagine lumps of limestones to be the petrified ova of some fish. We now know this is not the case; these little rounded atoms are merely the results of mineral changes which the rocks have undergone after their original accumulation; we can observe similar "Pisolites," as they are called, forming in "Travertins," or modern calcareous accumulations precipitated from hot springs in several parts of Italy.

The Oolitic age has been very appropriately designated the "age of reptiles." It certainly was a period in which reptiles were the dominant creatures; and such is often their peculiarity of form that we may say to each,

"Thou comest in such a questionable shape."

When you examine the extraordinary things represented in my diagrams, I think you will admit that this Shakespearian passage is strictly applicable to them. Were I to describe all the forms of animals that occur in this Oolitic age, I should detain you longer than our time will admit of my doing; so I must select certain salient ones upon which to dwell. We still discover remains of the lower form of animal life, such as the sponges, star-fishes, and Encrinites. The various types of marine shells now multiply in a very rapidly-increasing manner, compared with what we found to be the case in the rocks lower down in the geological scale. Not only so, but every individual species that we discover is new, and, in many cases, the large groups of species which we call *genera* are equally new. I will give one illustration of what I mean. I spoke to you of the Brachiopoda, those extraordinary shells which are so abundant in the Cambrian, Silurian, and Carboniferous ages. There are certain of these Brachiopoda represented by two well-known genera, which are the centres around which many other similar genera are grouped; I mean the genus Productus and the genus Spirifer. Now these two names represent two vast groups of species of shells, which occur in enormous numbers in the Palæozoic beds; but they have all gone out of existence, with the exception of one or two solitary forms that have just survived long enough to reach the base of this Oolitic age where they finally disappear. Ascending to the higher mollusca, we come to a very remarkable change in the opposite direction. I spoke to you the other day of the existence of Cuttle-fishes in the ancient age, and pointed out that even in the Cambrian and Silurian beds we had shells that unquestionably belonged to that group of molluscs. There is living in the sea at the present day, especially in the seas of the Malay Archipelago, a well-known shell, designated the Nautilus. This Nautilus has a spiral shell, with numerous transverse partitions dividing its interior into a series of chambers, whilst the animal constructing the shell resides in a large terminal chamber. This means that originally there was but one chamber, in which the very young mollusc lived, but as the animal grew it enlarged its shell to make room for its growing body. If you look at the outline of the soft animal you will see that he has a rounded base, and that for it to have dwelt in the open mouth of a tapering cavity, where there was nothing to prevent his being incon-

veniently pressed backwards into the narrowing portion of a spiral cone, must have been far from comfortable. We should be in a similar position if required to sit in a large chair, the seat of which was made like an inverted extinguisher. But

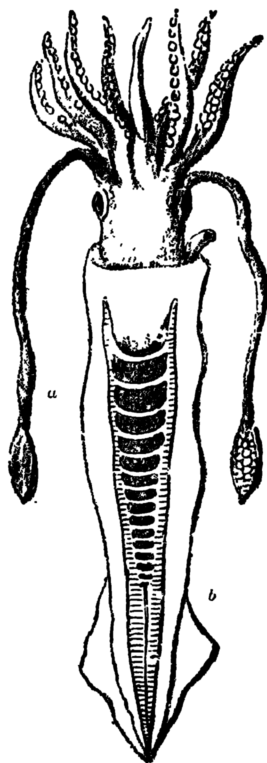


FIG. 6—Diagram of a Cuttle-fish containing a Belemnite. (*a*) Chambered shell of Phragmacone of the Belemnite. (*b*) Solid extremity of the Belemnite.

the Nautilus escapes from this uncomfortable position by shutting off behind it such portions of the shell as are too narrow for its body; it effects this by constructing a transverse partition of shell, the concavity of which fits accurately to the outline of the posterior part of its body. In whelks and periwinkles no

arrangement is needed, since, in them, the animal always corresponds in length and form to the entire cavity of its shell. The animal which makes itself comfortable in the way described is merely a modified Cuttle-fish. There are two great groups of these creatures, both of which are represented in a fossil state —viz. those whose shells enclosed their bodies, as in the Nautilus —and those whose bodies enclosed the shell, as in most of the Cuttle-fishes. Both these types abound in the Oolitic rocks. In a few cases the entire Cuttle-fish, with its contained chambered shell, is perfectly preserved. You will remember we believe this to have been the position of the gigantic Orthoceræ, met with in the rocks belonging to the Carboniferous and Silurian ages. That gigantic Cuttle-fishes formerly existed is probable enough, since a huge one has been discovered on three or four occasions living in the Atlantic, of which the body and arms together are more than thirty feet in length.

The study of these Cephalopods, as the entire group of Nautili and Cuttle-fishes is called, affords an interesting illustration of the progress of life on the globe. In the Cambrian and Silurian ages we had true Nautili and Cuttle-fishes, and in the Carboniferous age we again find similar objects; but associated with the former we now find a new nautiloid shell, called Goniatites, to be very abundant. There is a bed of ironstone, called Ganister running through our Yorkshire and Lancashire uplands, which is full of these Goniatites; this genus is essentially characteristic of the Carboniferous age. When we come to the Triassic age we find that the Goniatites are gone, and are now represented by another genus, the Ceratites. On crossing the boundary separating the Trias from the Oolites, we find that the Ceratite has disappeared in its turn, but we find in vast numbers, associated with true Nautili, creatures known by the name of Ammonites. These Ammonites are spiral shells, like the Nautilus, with this difference, that while the divisions between the chambers in the Nautilus are simply concavo-convex, in the Ammonites their surfaces undulate in an extraordinary manner; so that their margins, as seen on the surface of the fossils, look more like the foliage of a tree than anything connected with molluscan life. These Ammonites accompany us all through the Oolitic period; from the Liassic rocks up to the top of the Chalk which surmounts the Oolitic pile of strata, they are extremely common, but they are confined to the rocks of the Oolitic and Cretaceous ages. Associated with these Ammonites throughout the same periods

we find true Cuttle-fishes, and also curious fossils, which have long been known to the provincial mind as "thunderbolts." In shape they remind us somewhat of Sir Jos. Whitworth's pointed shot and shell. Formerly it was the popular belief that every flash of lightning was accompanied by the fall of a "thunderbolt;" and the ignorant multitude identified these oblong fossils with the supposed electric product. They are, however, merely chambered shells, somewhat like the Palæozoic Orthoceras, but in which the chambered portion occupies only the upper and inner part, whilst the lower part is weighted by a solid, investing, semi-crystalline mass.

In the Cretaceous period other Nautiloid forms known as Hamites, Ceratites, &c., abound—forms only found in the Cretaceous strata—but on entering the Tertiary age all these Oolitic and Cretaceous types pass away leaving only forms of Nautili and Cuttle fishes, similar to those which still flourish in our existing seas.

Leaving these mollusca and advancing to a higher stage, we come to fishes and reptiles, and here it is that the marvels of the Oolitic age begin to present themselves. The fishes are still confined to the two groups, the *Ganoids* of Agassiz and that containing the sharks and rays, but in many of the Ganoids we now find, for the first time, the posterior extremity of the vertebral column terminating on the centre of the tail. (See Fig. 9.)

It would be vain to attempt to dwell upon a tenth part of the reptilian forms that characterise this age; I can only select a few of them. The seas in which these reptiles lived were probably tropical, since, in many parts of the range of hills extending from the coast near Scarborough to the banks of the Severn, we find the limestones abounding in corals of the tropical type and not unfrequently existing in the form of true coral-reefs. One of the strangest of the reptiles is the Ichthyosaurus; a formidable creature of great size and power, aquatic in its habits. When I tell you that he was often from 20 to 30 feet long, that I have seen the teeth three inches in length, and that his immense head is furnished with long rows of them, you will admit that he is not exactly the kind of creature one would like to encounter when bathing. Associated with this gigantic fellow, was the gentler and more graceful animal called the Plesiosaurus. He lived in the same seas, and was, like the Ichthyosaurus, an aquatic animal; both of them were carnivorous; of that there is no doubt, because in some of the

specimens, we have actually found in the place where the stomach ought to have been, the remains of their last meal, and can thus identify the fishes upon which they fed. Leaving these great Ichthyosaurian reptiles, I come to another huge creature known by the name of Megalosaurus. This was a gigantic land reptile, constructed somewhat like a kangaroo, with the hind limbs prodigiously large in proportion to the



FIG. 7.—Skeleton of the Pterodactyle. (*a*) Four free inner digits furnished with terminal claws. (*bb*) Outer digits sustaining the membranous wings.

fore ones; whether these gigantic hind limbs were made for leaping or for running we do not know. Another saurian is called the Cetiosaurus, meaning the whale-like saurian, of which a fine series of bones is preserved in the Oxford Museum. This creature was evidently built in the heavy type of the whale; at the same time there is no doubt he was a true reptilian animal. In the Museum at Whitby you will

find the remains of several other saurians, including those of a Teleosaurus or crocodile, with a long and narrow head and snout. It so happens that this creature has left a very near relation in the world. Those who have visited India and dipped into the Ganges may know something of the Indian crocodile, known by the name of the Gavial, which is extremely like the Teleosaurus; the latter was doubtless an amphibious creature, equally prepared to take a meal on land or in water, wherever he could best catch one. Still more marvellous is the Pterodactyle, a huge flying reptile whose name merely means that his digits supported wings; and there is no question that this creature was a real flying dragon; probably the only real flying dragon the world ever saw, since those of ancient fables certainly have no existence. When this fellow's wings were outspread they sometimes measured fifteen feet from tip to tip. I think you will say that the Roc was not more likely to alarm poor Sinbad the Sailor than one of these Pterodactyles would have done had it swept past him into the valley of diamonds. When we come to the Wealden beds, which are a local group intermediate between the Oolitic and Cretaceous series, we find these Pterodactyles associated with another wonderful group discovered by my old friend, the late Dr. Mantell, the well-known Sussex geologist. These new forms correspond with the Iguana, a large lizard found at the present day in the West Indies. Here again gigantic size characterised our objects. I remember Mantell showing me, in his collection, a thigh-bone of one of these lizards, which was four feet eight inches long, and of proportionate thickness, even in its imperfect state. Now realise what that means—a lizard with a thigh-bone four feet eight inches long. If you examine the thigh-bone of any living crocodile, you will find it less than a foot in length. From this comparison you will be able to estimate the proportions of these ancient monsters. I have in my own cabinet a fragment of one of these thigh-bones, the dimensions of which when entire must have been even greater than those I have named. Remembering the above facts, I think you will acknowledge the perfect appropriateness of the declaration that the Oolitic and Cretaceous rocks belong to "The Reptilian Age." But we have not yet done with the animals of this period. At Solenhofen, in Bavaria, whence we get our lithographic stones, the skeleton of a bird has lately been found. The notable feature of this bird is seen in his tail, which was long, slender, and tapering, reminding

us of the tail of a lizard. If you examine living birds you will find that, in every case, the bony members of their tails are not only short and compact, but all their tail-feathers are attached to the very last joint of the tail, which is enlarged to allow of their being planted upon it. I repeat that in all living birds the entire series of the tail-feathers is attached solely to the last joint of the tail and to no other; but when we examine this very remarkable fossil-bird we find not only a long tail, but each of its bones has one pair of feathers attached to it and no more. There are twenty pairs of true feathers. Such is the earliest form in which indisputable remains of birds present themselves to our notice. I may remind you here that no fragments of the skeletons of the supposed birds which produced the Triassic footsteps of the Connecticut Valley have yet been discovered. Strangely enough, out of the enormous number of these creatures that must have existed, not one solitary fragment of bone, feather, or tooth has been found to give a clue to the nature of the animals that thus left their footprints on the sands. If these were birds, of course the one now under our notice came very late into the world; if they were not birds, but two-legged reptiles, as some geologists believe—then this Archæopterix is the oldest bird with which we are acquainted.

I have yet to say a word about the flora of the Oolitic age, which consists either of the Conifers, plants of the pine tribe, or of the remarkable allied group known as Cycads, to which I have already called your attention. Through the Oolitic age we find no trace whatever of the modern types of forest trees; not one solitary leaf, fruit, seed, or fragment of wood of any kind has been obtained that indicates the presence of any other type of arborescent plant than the firs or pines, and these remarkable Cycads. There is no doubt whatever that the characteristic vegetation of this age was Cycadean.

I have already mentioned the discovery of a few teeth of a true mamma near the junction of the Triassic and Oolitic rocks. We meet with other mammalian remains in the Stonesfield slate, a thin bed belonging to the middle of the Oolitic series. These latter also are either Marsupial, like the Opossums, or Insectivorous, and allied to the Hedgehogs. A third group of these fossils has been found at the upper part of the Oolites in what are called the Purbeck beds. These too are chiefly either Marsupial or Insectivorous—but amongst them are some other

bones that may possibly belong to other classes of mammals, and which require further investigation.

But our time is slipping away, and we must now cross another boundary line and come to the Chalk. The Cretaceous beds are sometimes made up of sands and sometimes of chalk itself; the latter reveals to us a remarkable fact which the great German microscopist, Ehrenberg, was the first to find

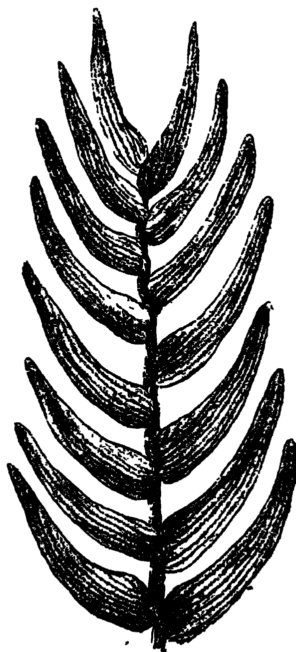


FIG 8.—Part of a Pinnated Cycadean leaf.

out. If you take a fragment of soft chalk from a Cambridge quarry, you can easily brush it away in water until you resolve it into white mud. Put a little of this mud under the microscope, and you will discover that it is literally made up of the little objects known as Foraminifera.

We have here evidence of the truth of what I told you the

other day, viz., that some limestones, at all events, were not the products of any chemical action operating in the sea, but resulted from the agency of living creatures. As I have already stated, I am perfectly satisfied that the same remark can be made in reference to every limestone rock in existence, excepting those few fresh water Travertins about which I spoke an hour ago, and which are too insignificant in their amount to be taken into consideration when explaining the origin of limestone rocks. The Foraminifera which constitute chalk are very nearly related to the species filling up the bed of the Atlantic, and other seas in many parts of the globe, at the present day. Along with these Foraminifera, we now find an enormous number of organisms of various kinds which we have not met with previously. Thus during the Chalk age, sponges were at least more numerous and varied than at any previous period. At all events the number both of types and of individuals occurring in the Cretaceous strata many times exceeds what we find in any other part of the geological series. We also now find new forms of star-fishes, as well as of the tribe of sea-urchins so common on some parts of our sea coast; but many of these new fossils present forms characteristic of the Chalk age and not found in any other rocks Turning to the Encrinites we again find a change. Most of the old types have gone, and are now represented by the extraordinary creature known as the Marsupite, from *marsupium*, a purse. This is simply an Encrinite without a footstalk. He had no footstalk, at least when grown up, though what he may have had in his babyhood I do not know. Star-fishes are living in the Frith of Clyde, which, in their infantile days, are supported upon a footstalk, but when they grow larger they detach themselves from it and float free. These Marsupites may have done the same. At all events the genus is very characteristic of the Cretaceous rocks. We still find remains of the Pterodactyle, the Mososaurus and the Ichthyosaurus. The Plesiosaurus is no longer there, but it is represented by the Pleiosaurus which much resembles it; these peculiar reptiles survived in diminished numbers, but as we leave the Cretaceous age they pass out of existence, to be replaced, as we shall see in our next lecture, by the modern types of lizards and crocodiles.

I have already spoken of the multiplication in the Cretaceous deposits of forms of shells allied to the Ammonite, and of

their final disappearance, along with the Belemnite, at this epoch.

But there are other remarkable vertebrate creatures yet requiring our attention. Two diagrams before you represent the lower jaws of two species of bird that have been discovered in the western regions of North America, by Professor Marsh, one of the first naturalists of America, who has found, at least, thirteen species of fossil-birds in the rocks of ths Cretaceous age. Some of these were met with on the Atlantic coast, and others in the far district of Colorado; the feature that is so remarkable about some of them, is that their beaks are furnished with rows of teeth as regular and definite as are those of any reptiles. This is a marvellous and unexpected fact. We have no bird with teeth at the present day. Anatomists of the evolutionist school naturally refer to these birds as indicating a transition state between reptilian forms and modern types of bird-organisation, and it is unquestionably true that they have very strong reasons for arriving at this conclusion. It is unquestionable that these objects are true teeth, each having a fang at its base, and having the upper part of each tooth covered with true enamel. Then the teeth are sometimes planted in a row of distinct sockets, whilst in others they are fixed in a groove, which shows a gradual approximation towards the development of sockets. Teeth like these must have belonged to carnivorous creatures. The two birds to which I am referring were both aquatic. One of them was about the size of a pigeon; but the other was a large diver, measuring about six feet from the tip of the beak to the end of the toes. It was a powerful bird, but, like the living Penguin, was unable to fly. Its wings were merely rudimentary ones. The supposition that this bird represents a form intermediate between the bird and the reptile, is further sustained by the circumstance, that, at the extremity of the upper jaw of this species, there were no teeth, but the jaw appears to have terminated in a horny beak. So that you have here combined the reptilian tooth with the beak of an ordinary bird; according to the evolutionists, as time went on, the beak grew bigger and the teeth grew less, until the latter finally disappeared. Thus there was handed down to future ages the race of feathered descendants which we see around us at the present day.

An extraordinary change came over the vegetation of the

world during the Cretaceous age; a change which not only affected the plants themselves, but the results of which reveal some remarkable phenomena connected with the distribution of heat and cold over the earth. In both the lower and upper parts of this Cretaceous series, we now find, for the first time, the representatives of living plants belonging to the flowering tribes comprehended under the name of Dicotyledons, and many of which are closely related to trees now flourishing in the forests of the world. We now come upon species of fig-tree, oak, beech, poplar, myrtle, willow, and magnolia, along with pines, ferns, and a host of other allied plants. The oldest of these Dicotyledonous plants with which we are acquainted is a species of poplar. We have seen that up to the commencement of the Cretaceous epoch, the only known plants have been pines, Cycads, and the various forms of cryptogamic vegetation; but recent discoveries have brought to light such a multitude of the higher forms of vegetation, from various parts of the world, that my two friends, Professor Heer, of Zurich, and Professor Lesquereux, of Columbus, United States, who are investigating these plants, run a fair risk of being overwhelmed by the multitude of specimens accumulating in their hands.

The climatal features to which I referred are quite as remarkable as the rapidity with which these new forms of vegetation multiplied and spread over the earth. Many of the specimens of this new vegetation have been brought to us from Greenland, a country which is now covered with ice, and where not a stick or leaf of a living tree will now grow; where, in fact, there is no vegetative life excepting the herbaceous plants that spring up during the brief summer. And yet in the age of which I am speaking, Greenland possessed magnificent forests, similar in many respects to those which now flourish in the warm Southern States of North America.

If you hunt through the forests of England and of midland Europe, you discover no species of magnolia or myrtle, fig-tree or Cycad, Tree-fern or Oleander, yet all these flourished in the ancient forests of Greenland. Some stupendous changes have evidently been wrought in the world since those days. It is very clear that the distribution of snow and ice was very different then from what it is now. Whether the earth's axis has got a twist, or whether in those days the globe was

whirling through some warmer parts of space than now surrounds us, is not easy to determine. The probabilities are against the idea of any change in the poles of the earth; but something strange must have occurred since the time when not only forests of magnificent trees overspread that Greenland continent, but when tropical genera of ferns, such as the Gleicheniæ, flourished as an undergrowth in even greater numbers than is the case with these ferns in tropical forests at the present day.

THE SUCCESSION OF LIFE ON THE EARTH.

LECTURE III.

THE physical and vital agencies which modified the crust of the earth and its inhabitants through the long periods which occupied our attention in my first two Lectures, did not cease their action at the close of the Cretaceous age. They are producing similar effects now to those which they caused in the beginning of time, and probably with undiminished energy. But for a long period the effect produced by those agencies, subsequently to the Cretaceous age, were very ill understood. Until the early part of the present century what we now call the Tertiary rocks were almost altogether neglected. Baron Cuvier—one of the greatest of European naturalists—first showed the world that the Tertiary deposits in the neighbourhood of Paris contained the remains of strange and extinct animals. This discovery opened the eyes of geologists to the fact that there existed a series of superficial deposits, which eminently merited any amount of labour that might be bestowed upon them.

The important discoveries of Cuvier made a powerful impression on that great geologist whose death we had so lately to deplore—I mean Sir Charles Lyell. Lyell undertook the study of these neglected Tertiary beds. He endeavoured, and with a large amount of success, to reduce them to order by making use of the fossil shells which they contain. I may observe here that in all probability, if we except some Foraminiferous creatures of low organization, no one species either of plant or animal that lived previous to the close of the Chalk age, survived that period. Except one doubtful shell all the species found in the Mezozoic strata became extinct. None of them are to be found in any of the Tertiary strata. You will understand, however, the limitation with which I make this utterance. If the doctrine of evolution be true we are all descendants of species that lived prior to the Chalk age.

But naturalists have hitherto applied the term "species" to individuals, the probability of whose descent from common parents is indicated, by the identity of their organization; groups of organisms are regarded, as being of the same species, when their individual members, are more like one another than they are like any other objects. The term species being thus defined, it becomes true, that all the Tertiary species are different from those which lived previous to the close of the Cretaceous age. Still less could any of the latter be identified with such as are now living on the earth. But when we cross the boundary line that separates the Cretaceous rocks from the Tertiary deposits, we begin to find the fossil remains of species that are still living. Lyell made use of this fact, and based upon it his classification of the Tertiary strata that we are about to study. He found that in the oldest of these Tertiary beds there was not more than about three and a half per cent. of recent shells in every hundred fossil species that he examined. Therefore he threw these oldest beds into one group, to which he gave the name of Eocene—a term signifying the dawn of recent life. In strata of newer age he found something like thirty-five per cent of living shells, associated with sixty-five per cent. of extinct ones. To this group of deposits he gave the name of Miocene—or less recent. Then when he came to other deposits of still more modern date, he found that the proportion varied from forty or fifty per cent. up to very nearly 100 per cent.; and to these he gave the name of Pliocene, or more recent.

The deposits to which Cuvier's attention was chiefly directed belonged to the Eocene period of life. I need not dwell upon the vast multitudes of shells that were found in them, though many of these were peculiar, including numerous genera not met with in the older rocks but which are amongst the most common of those now living. We thus learn that on crossing from the Cretaceous to the Tertiary beds even the molluscan forms of life underwent a sudden change. This is equally true of those which ceased to exist and of those which now appear for the first time. I have already pointed out in how marked a manner this statement applies to the Cephalopoda, or animals allied to the Nautilus and cuttle-fishes.

In our own country these Eocene strata are only found in the south-east of England, and especially in the neighbourhood of London and the Isle of Wight. In them we find the remains of reptiles, birds, and mammals. But the Ichthyosaurus and its

companions are now replaced by the crocodile and the serpent. The latter creatures were as large as the tropical Boa-constrictors of the present day, and amongst them there was, according to Owen, a huge and veritable sea-serpent—though not having yet caught *the* great sea-serpent, I am not quite clear as to what his anatomical characteristics are. Then we have numerous turtles—rather smaller than the recent ones seen at aldermanic feasts. Fishes of many varieties now abound. The modern types which first presented themselves in the Chalk age now become the prevailing forms—replacing the Mezozoic and Palæozoic Ganoids which, though still represented become comparatively rare. Figure 9 represents the

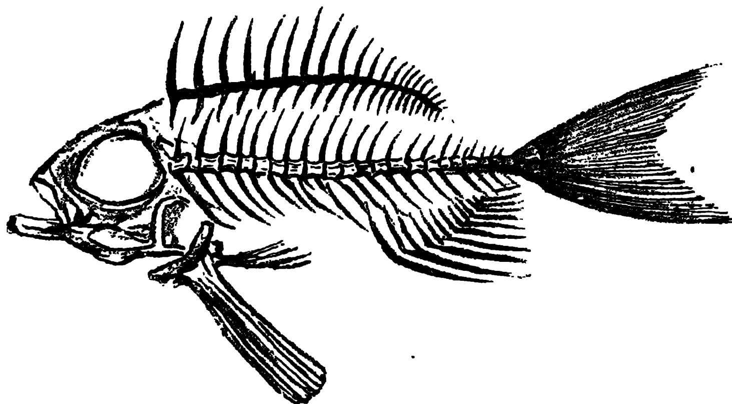


FIG. 9.—Skeleton of a perch of the Eocene period, displaying the homocercal tail

skeleton of a species of perch, from the slate-quarries of Glarus in Switzerland. This skeleton exhibits the *homocercal* tail, to which reference was made in a previous lecture. At the latter part of the Cretaceous age we find for the first time fishes allied to the salmon, perch, and many other forms living in our seas and rivers at the present time. You will probably remember I told you that no solitary fragment of those modern types of fishes to which Agassiz gave the name of Cycloids and Ctenoids, from peculiarities seen in the forms of their rounded scales, had hitherto been met with in rocks older than the Cretaceous series; but towards the upper part of that group they begin to appear, and when we cross the

boundary and come to the Tertiary deposits these fishes crowd upon us in great numbers. Sharks of huge size were also common, as is shown by their numerous teeth preserved in the Eocene beds. But it is when we come to the Mammals, especially to those first discovered by Cuvier, that we are most strongly reminded of the changes which have overtaken the world's fauna.

When Cuvier first discovered the bones of these creatures he showed to the scientific world, that, from the study of a limited number of bones, he could reproduce, with considerable probability, the entire animal. He did this by means of what he designated the law of co-relation, or, in other words, the mutual dependence of parts upon each other. That such restorations are possible within defined limits is doubtless true; but when I hear of their being accomplished by the examination of a fragment of bone or of a tooth, I can merely smile at the world's credulity. If the combination of organs in the extinct animals had exactly corresponded with what we see in living ones, such feats of anatomical legerdemain might have been possible. But no man only possessing the skull of a Pterodactyle would have given to the animal the wings of a bat; neither would acquaintance with the skeleton of the body of Marsh's large Diver have led its discoverer to connect with it jaws full of enamelled teeth.

The chief quadrupeds which Cuvier found in these deposits were of two types; one of these was a heavy creature, somewhat like the pig; the other was an animal of much lighter construction. Cuvier showed, what we have no doubt now is perfectly true, that these were Mammalian animals, very closely allied to the Tapirs of which herds now roam through the South American forests.

The Tapir is a hog-like creature, but nevertheless not a true pig. It had its upper lip prolonged into a sort of proboscis, which was also the case with the Palæotherium. But Cuvier's other discovery, the Anoplotherium, was a creature of a much more graceful structure, and approached somewhat nearer to the Antelopes. The remains of these creatures are found not only at various points on the continent of Europe, but in England. Another Eocene mammal is the Hyænodon, which was probably one of the oldest of true carnivorous mammals.

We now meet with another well known group of animals not found in older strata—I mean the whales. In this lowest Eocene deposit there has been found, especially in the United

States of America, a huge whale furnished with very remarkable teeth, and known by the name of the Zeuglodon, and we know for a certainty that some of these Zeuglodons were fully seventy feet in length. Thus you see that though the giant Ichthyosaurus and other allied aquatic reptiles have disappeared from the sea, other huge marine creatures have taken their place, though of an entirely different class.

The general conclusion to which we are brought by the study of the animals found in these Eocene deposits is that at the period in which they were accumulated, the animal life on the globe was of a somewhat tropical character. This conclusion is further confirmed by the study of the plants of that age. We now find tropical palms, and associated

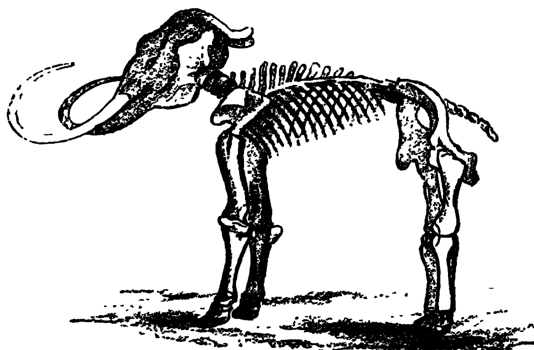


Fig. 10 —Skeleton of the Mammoth.

with them we have a large number of other plants, the seeds and fruits of which are yet preserved, all indicating the same general fact, namely, that the temperature at the period in question was very high.

But we must now cross another threshold and enter upon the Miocene age—in which we discover a marvellous outburst of that animal life, living forms of which now constitute so conspicuous a feature in the forests of India and Africa. We have probably no trace of these Miocene deposits in England; but when we cross to the Continent, we find them here and there in detached patches. As we proceed to the flanks of the Alps they crop up in larger masses, and an enormous range of them runs along the southern flank of the Himalayan

hills; these deposits are rich beyond any precedent in the remains of gigantic animals very similar to some now living. This remark applies to the Miocene deposits in various parts of the old and new world. We have now the Mammoth and the Mastodon—huge forms of Elephants; then we have the Hippopotamus, Rhinoceros, Bear, Hyæna, Monkey, Giraffe, Camel, and Deer of numerous forms. The Dinotherium was a huge elephantine animal but with two tusks projecting downwards from the lower jaw. The Sivatherium found in India, was a stag-like ruminant with two pairs of horns, and associated with it was a gigantic Tortoise eighteen feet long! I have said enough to show how marvellous and rapid has been the outburst of new forms of animal life, contrasted with its slow development in previous ages.

In dealing with the question of evolution we have carefully to consider the facts which I am now briefly enumerating. Recollect how extremely insignificant the thickness of the deposits that we are speaking of is compared with those of earlier date. The entire series of Tertiary beds is only represented by a very thin line even in any large section of the stratified rocks drawn to one scale. Yet, as I have already shown, the thickness of a series of deposits constitutes our best standard, imperfect though it be, for measuring the time which those deposits occupied in their accumulation. Remember then that in the lowermost part of the Tertiary series we have scarcely any of these mammals. The few found in beds of the Eocene period are but scanty representatives of the group; but when we turn a corner, it appears as if some great magician had waved his wand and, in response to the magic summons, life of the most varied character, and in forms most dissimilar from what immediately preceded, flash into existence.

The evolutionist has to explain these unprecedented phenomena, and to ascertain, if he can, how it is that this development of animal forms has proceeded so slowly through millions of years, and then at a very late period, as if in preparation for man's advent upon the earth, it should suddenly advance with such amazing rapidity. I contend stoutly that however numerous may be the facts that sustain the doctrine of evolution (and I am prepared to admit that there are many that do so in a remarkable manner) this unexplained outburst of new life, demands the recognition of some factor not hitherto admitted into the calculations of the evolutionist school.

Before we finally leave the Miocene age I would call your attention to the imperfect knowledge, not only of fossils, but of anatomy, which prevailed amongst naturalists in the early part of the last century. Scheuchzer, one of the most eminent naturalists of his day, obtained a skeleton of a large newt or Salamander from a quarry at Œningen, whence many similar skeletons have since been obtained. This he described, in more than one work, as the skeleton of a man who had been drowned in the Noachian Deluge. The fact that this Salamander rejoiced in the possession of a tail seems to have constituted no difficulty in the way of this primitive geologist. Both in size and form the Œningen reptile approaches very closely to a living Japanese species.

Leaving the Miocene we come to the Pliocene period, which has left its memorials, in the south-eastern counties of our own



FIG 11.—(a) Œdipoda Haidingeri, a grasshopper from the Miocene beds of Radoboj in Croatia (after Heer). (b) Schellenbergia rotundata. A Miocene spider from Œningen in Switzerland (after Heer).

country in what is called the Crag of Suffolk, as well as in other parts of the world; we still find scattered amongst these deposits the remains of most of the Miocene Mammalia which continued to flourish, though the climate became much more temperate than it formerly was.

The detached Pliocene deposits are doubtless of various ages —but throughout the entire series we find numerous, still living, species either of marine or fresh-water shells; but curious changes have occurred in some of these species. Some which were very common in the Pliocene seas are now rare on our coasts, whilst with others the reverse is the case. There is no doubt that these shells indicate a change from tropical to temperate conditions. Nevertheless some of the

marine objects continue to be very remarkable. This is especially the case with the sharks, of which the fossil teeth are very numerous in what are called the Crag deposits. Many of these teeth are of enormous size. Comparing them with those of large living sharks, and assuming that the magnitude of the jaws increased in the same ratio as the teeth, we may fairly conclude that some of these fishes must have been able to open a mouth wide enough to take in the contents of a London Omnibus at one bite. Along with remains of the shark we now find bones of the true whale. These are not the Zeuglodons of the Eocene age, but whales of the modern type.

As the Tertiary age advanced we discover that the living types of vegetation became more and more abundant. You will recollect I called your attention to the fact that even at the close of the Cretaceous age poplars, myrtles, magnolias, and a whole host of other Dicotyledonous trees, belonging to warmer climes than ours, had begun to make their appearance on the earth. As the Miocene age passed by we find that the genera and species of these trees multiplied quite as rapidly as the quadrupeds. We further learn from the fossil plants that the distribution of heat and cold on the earth continued to be very different from what it now is. Thus, even in the Miocene age, parts at least of the ice-clad continent of Greenland were still clothed with rich semi-tropical forests in which district forms of plants were almost as abundant as they were at the close of the Cretaceous period. When those northern regions assumed their present condition we have yet to learn; but the change was probably coæval with the similar ones which affected the entire northern hemisphere after the close of the Pliocene epoch.

An age arrived when the semi-tropical conditions that prevailed in the periods of which I have been speaking, gradually yielded to influences of a more chilling character. Ice and snow began to creep southwards from the Arctic regions, until at last there arrived a time, now known as the Glacial age, in which the greater part of the northern hemisphere was covered with ice and snow, much in the way that Greenland is so clothed at the present time. How long this condition of things continued we do not know; but you will readily understand that such a physical change would necessarily produce great alterations in the life of the period; and geology affords us proof that this was the case. We now find the Reindeer

feeding at the foot of the Alps; its remains, along with those of the Musk ox, supplies of which animal, you remember, made a welcome addition to the scanty larder of the late

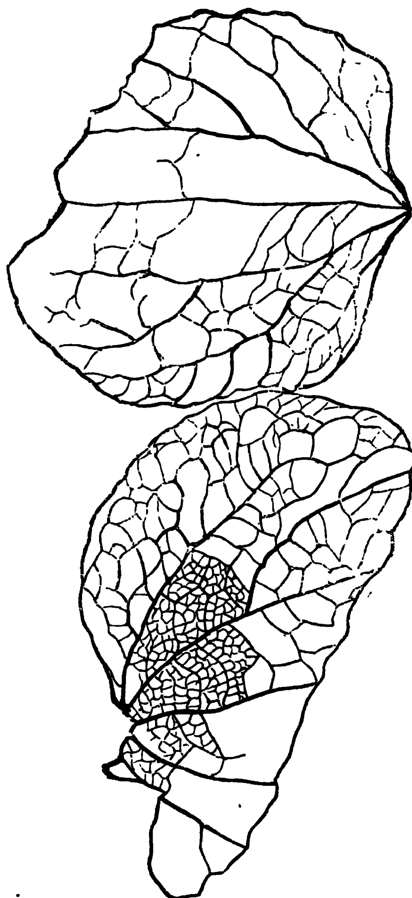


FIG. 12.—Leaves of a Miocene species of Poplar (*Populus arctica*) from Greenland (after Heer).

Arctic explorers, occur over the whole of northern and temperate Europe, including our own country. The Glutton, another Arctic animal, has also been found in a fossil state in some of these glacial deposits. To give even an outline of the history

of this age would require a dozen lectures in order to do the subject justice. I should have to unfold to you the history of those wonderful ossiferous caverns which have been found in various parts of the world, and the investigations of which have been productive of such remarkable results. But time will not allow me to dwell upon these matters, beyond pointing out to you some of the more characteristic phenomena. On studying the Tertiary age generally, we cannot fail to see how much the world changed in one point as it grew older. At those periods which we examined in the two first lectures, we have every reason for supposing that animal and vegetable life presented a far greater uniformity than now from the Arctic to the Antarctic zones. Thus we find that the plants of the Coal measures of Australia are almost identical with those found in the Coal measures of Greenland and Spitzbergen, and the remark is equally true of the Coal measures of the intermediate zones. As the world grew older, and as we approach nearer to recent times, we find gradually springing up a tendency to local differences in the life characterising the different geographical areas; but at length we reach a period in which every country seems to have had its own distinctive animals, just as it has now. If I take you at the present day to the woods of South America, what do we find there? Amongst other things, numerous small Sloths hanging upon the trees, and feeding upon their leaves. In the Post pliocene age Sloths were common in the same region, but they were as big as oxen, and consequently altogether unfitted for climbing up trees; but, as Professor Owen has shown, they were fitted for pulling the trees down. The same American province now abounds in Armadillos, which burrow into the soft soil as rabbits do in our own warrens; but amongst these we find the remains of an enormous extinct Armadillo, which must have been as big as a carrier's covered van. He was certainly above nine feet long from snout to tail.

If we cross to New Zealand, what do we find there? At the present time we have no Mammalia in New Zealand other than a rat and a bat. This fact possibly explains why the old New Zealanders were cannibal; if you realise that they had no domesticated animals such as we have, and that the only chance of getting meat was to eat their enemies, we can scarcely wonder that a savage race should see no harm in doing so. There has been found along with this rat and bat, the

Apteryx, a small species of wingless bird, about the size of a Cochin-China fowl. This bird belonged to the same group as the Cassowaries of Australia and New Britain. In the later Post-pliocene days, birds of this class were extremely numerous in New Zealand; but instead of resembling the living Apteryx in size, they were often larger than any living ostriches, some of them being fully ten feet high. Their bones are now scattered abundantly over the length and breadth of New Zealand; and it is clear that their extinction was due to the same agencies as destroyed the Dodo of the Mauritius. They were eaten by the natives as long as any remained; and when this game was no longer available, the New Zealander would be more likely than ever to eat his fellow-men.

A species allied to these New Zealand Moas, as they are called, has been found in Madagascar; we have also got the eggs, and it is calculated that one of them would contain about 148 modern hen's eggs. Thus you see that both in South America and New Zealand the animals that still live there are the representatives of others which lived in the same countries during a bygone age; but the living forms are the dwarfed representatives of the older giant race. In Australia the living animals are chiefly of the Kangaroo type, of which there are enormous numbers, both as regards individuals and species; and the remarks I made about New Zealand apply equally to Australia. We find in the caves of Australia fossil Kangaroos of the Post-pliocene age, and they were as much larger than those now living as the Megatheria and Moas of South America and New Zealand were larger than the Sloths and wingless birds of the present time. The point which I urge upon your attention is this—that the geographical distribution of animals at the present day does not differ, in many cases, from that which characterised the later geological ages. In the northern hemisphere this is true with an important limitation. We have already seen how during the Tertiary period the numerous Mammoths and their huge companions spread over the entire hemisphere. Then came the Ice age, which drove these creatures southwards, though we have evidence that both the Mammoth and the Rhinoceros were clothed with a covering of wool and hair, enabling them to endure a colder climate than can be borne by their modern representatives. At the same time they never were Arctic animals. They must have had vegetation upon which they could browze, and their companion, the Hippopotamus, must

have had unfrozen rivers in which it could swim. After the great invasion of ice passed away many of these animals returned to their old haunts; but they gradually disappeared one by one, leaving behind them only the wolf, the bear, the elk, and the deer to represent them in the temperate portions of the northern hemisphere at the present day—the larger forms of animals which formerly were their companions, and characteristic of the same great zoological province, having now retreated to the forests of Southern Asia.

After a period of unknown duration the ice began to recede northwards owing to a return of more genial suns. There is much difference of opinion amongst geologists as to the detailed succession of events during this age of milder temperature, but it is obvious that a struggle between sun and frost continued for a long period. There is much reason for supposing that after the first great Glacial age, the ice so far disappeared as to leave extensive tracts of land over which the Pre-glacial animals spread themselves, and that this very variable "Inter-glacial" period was succeeded by a return of the ice-sheet which again overspread parts of the temperate zone. Be this as it may, the ice sheet finally disappeared, but its remnants lingered in the shape of numerous glaciers which long continued to occupy the gorges of our mountainous regions. During this later time the Mammoth and many of its Pre-glacial companions still roamed to and fro amongst our lower valleys and over our wide plains. At that time our island was not only united to the continent of Europe, but, in all probability, stretched far away southward and westward into the Atlantic. So that the ancient Europeo-Asiatic fauna was also the fauna of what is now Great Britain. The way in which the bones of southern forms of Mammalian life have become intermingled in caves and other Post-pliocene deposits makes their history a difficult one to render intelligible. This much however is certain. One by one these huge Mammals passed away from these latitudes. In all probability the latest survivor of the vast herds which once covered central Europe, but which do so no longer, was the noble species of deer known as the Irish elk; magnificent horns of this animal have been found varying from ten to fourteen feet from tip to tip, whilst his height was not less than ten feet; various facts have been brought to light, making it almost certain that this animal, at least, finally became extinct through human agency.

We now come to the most remarkable of all the phenomena connected with the history of life on the earth. I mean the appearance of man. Few are ignorant of the discussions which have taken place on this point, and of the wide differences of opinion that still exist in reference to it. On the one hand, there are geologists who believe that man existed in the age that preceded the first great invasion of Europe by the ice-sheet. Others who reject this conclusion admit that he must have dwelt in Europe in the Inter-glacial age, whilst a third school of *savants* deem the evidence of even this degree of antiquity unsatisfactory, but suppose that he came hither after the final disappearance of the ice sheet. But there are few, even of the latter class of geologists, who deny that man's antiquity as a dweller on the earth was very great; few who do not admit that he saw the Mammoth and the Reindeer feeding on the plains of southern France, and hence that he dwelt as a hunter amongst the many extinct Mammals whose names I have brought before you.

But before I deal with some of the evidence upon which we must base our conclusions respecting man's age, I must direct your attention to the history of one Tertiary and Post-tertiary group of animals which have assumed the highest interest in in consequence of the speculations of Professor Huxley in reference to it.

You all know that each foot of the horse has only one toe, which bears its nail or hoof. But every farrier is aware that on each side of the "cannon" bone there are two "splint" bones, and which are undoubtedly the degraded remnants of the second and fourth toes of the ordinary five-toed Mammalian foot. The two outermost toes, viz.: the first and the fifth, are altogether wanting, and in the case of the second and fourth the "metacarpals" and "metatarsals" as they are called—that is the bones which form the palm of the hand and the arch of the foot—are present in the shape of the two "splint" bones to which I have referred. Unlike the third toe, these two lateral splint bones have no digits, *i.e.*, proper toes or fingers, at their free ends. But Professor Huxley long ago called attention to the fact that in Post-pliocene times, when our modern horse had no existence, there lived a species of horse the "Hippotherium" in which the two splint bones *were* terminated by digits, but which were too short to reach the ground and take any part in bearing the weight of the animal. Going still further back into the Tertiary age, Huxley pointed out

the remains of another animal, the Anchitherium, which resembled the horse in many of its features, but in which the subsidiary second and fourth toes, though still smaller than the principal central one, were yet capable of reaching the ground. Professor Huxley came to the conclusion that the Anchitherium had first developed into the Hipparion and the Hipparion into the horse, and that this history gave a very powerful support to the doctrine of evolution. He asks, Which is the more probable conclusion at which we can arrive: that Europe once sustained herds of Anchitheria, which were swept away, to be replaced, through some miraculous agency, with similar herds of Hipparions, whilst these in like manner were supplanted by herds of horses of the modern type; or that, by a process of evolution, each of these successive types has been developed out of the pre-existing one? Huxley unhesitatingly accepts the latter alternative, and argues that if this is the true history of the horse, something similar to it must have been equally the history of all other animals.

Two questions arise out of this hypothesis: first, is this a correct account of the genealogy of the horse, and, if so, does it follow that all other animals must have had a similar genealogy. In endeavouring to trace out the ancestry of beings whose pedigrees have not been preserved, but have to be ascertained by means of circumstantial evidence, we have but one kind of trustworthy evidence. If all the examples of Anchitherium exhibit peculiarities of a distinctive kind which separate them *by a definite line of demarcation* from the Hipparions, and if the latter in turn are equally distinct from the modern horse, we have no evidence that the three distinct gradations in the development of the foot were the result of a succession of minute and impalpable changes *in which one type shaded off into another*. Such gradations are met with in the organic kingdom in innumerable instances. But if, on the other hand, a long and linear series of specimens of these animals can be put before us exhibiting, not interrupted gradations, but such a gradual transition from the Anchitherium to the horse, as renders it impossible to discover a break in the long line, then Professor Huxley's conclusion that the Anchitherium was the ancestor of the Hipparion and the Hipparion of the horse, becomes inevitable, and we must accept it whatever other conclusions may be rendered necessary by our doing so. Until recently the evidence that there had been such a transmutation was not satisfactory

to me. But in a recent lecture Professor Huxley has brought forward some additional evidence derived from Professor Marsh's discoveries in the western states of North America. Beyond all question some of the gaps which have hitherto separated the three animals I have named, are filled up by these discoveries; but I want yet more evidence before I can arrive at the conclusion that the doctrine of evolution is proved by these facts beyond the possibility of question. It appears to me that before I can unhesitatingly give to the testimony of these fossil horses the full value which I am asked to do, I must know more about them than is at present possible. It will not be enough that the limbs and teeth of these creatures indicate transmutation, but such transmutation must be evidenced by every part of the animal. This demand is especially applicable to the stages which intervene between the Hipparion and the horse. If the latter was evolved out of the former during long periods of time, it must have been so evolved *as a whole;* not merely showing the gradual change progressing in some organs, but in every portion of its structure; myriads of individuals must have existed to effect this gradual shading of the one into the other in every part of its body. It is true that in the Pliohippus of Professor Marsh, the two lateral metacarpals had no digits, but even between this form and the abortive splint bone of the horse, there is yet a wide gap. Further researches may fill up this and other similar gaps. The facts now known undoubtedly increase the probability that the doctrine of evolution alone can explain the existence of this series of horse-like animals, but the recognition of this *probability* is a very different thing from the admission of absolute certainty, which is practically demanded of us.

But even admitting all that Professor Huxley requires us to do, so far as the genealogy of the horse is concerned, does it follow that we must at once recognize in evolution the process to which all other forms of organic life are due? To this question I can only give a negative answer. I have already expressed my conviction of the applicability of the doctrine to the explanation of many of the variations of organic life, and I think it impossible to exaggerate its value as a working hypothesis; but beyond this I am, as yet, unable to go and for this reason: assuming Professor Huxley's hypothetical genealogy of the horse to be historically true, it only demonstrates what we already believed to be a fact, viz., that

changes in the surroundings of living organisms were capable of producing corresponding changes in those organisms *within certain limits.* In the present case we have only one part of the problem solved by nature's experiment. We have only the degradation, from disuse, of certain pre-existing organs—a process which throws no light whatever upon the opposite class of facts, in which ntire organs make their appearance which had no previous existence. Animals already so closely allied to each other as to represent collectively the equine type, *began* with five toes, four of which successively disappear so far as only to be represented by the imperfect splint bones of the living horse, but we do not learn from these facts how animals originally became possessed of toes of any kind. Such information may be obtained from other sources or it may not—but the history of the horse certainly does *not* furnish us with it.

After this preliminary inquiry we may now proceed to ascertain what light has been thrown upon the corresponding history of man.

As is well known, numerous ancient relics have been found in various places, intimately associated with the remains of extinct animals, which no rational being can refuse to recognise as works of art fashioned by human hands. Rude works they are in many cases—but yet such as no unintelligent forces could have produced. The bone needle with its perforated eye, found by Mr. Pengelly in Kent's cavern, and the magnificent flint weapons which have been met with in so many localities, are illustrations of what I mean. The human origin of these objects being established, the all important point remaining to be proved is their age. Did the extinct animals, with whose bones these works of art are found associated, live into comparatively late ages, or did man exist in the remote period when Britain was a part of the European continent, and when the western extension of that continent stretched far out into the Atlantic?

There has been found one special set of memorials of a yet more interesting kind. I have already told you that as one of the consequences of the glacialisation of the northern hemisphere the Reindeer at one time abounded in southern France, where its remains now occur. Remarkable outlined sketches of these and other animals have been found in the same district, graven on pieces of their horns, on ivory, and on fragments of slate. In Sir John Lubbock's work

on the *Origin of Civilisation and the Primitive Condition of Man*, a book within the reach of all my hearers, you will see represented (p. 21) a group of Reindeer fighting, which was found in the south of France, and which could only have been delineated by some one familiar with these animals. In the same work is a still more remarkable outline scratched rudely on a piece of a Mammoth's tusk, and found in the Cave of La Madeleine in the Dordogne. From the sketch of the Mammoth given on page 90 it will be seen that the tusks of that animal curve upwards and inwards in a way that differs very widely from those of all living elephants; further, we know, from specimens found in Northern Siberia, that, unlike any of the living elephants, the anterior part of the Mammoth's body was hung with masses of long hair. Both these remarkable features reappear in the Dordogne sculpture. It seems to me extremely improbable that the ancient artist, even had he seen an African elephant —itself a very improbable supposition—would have so far diverged from his model as to reproduce exactly the two characters which distinguished the extinct Mammoth from its living representatives. The reproduction of one of these features would have been a remarkable coincidence; but that the two should be conjoined only appears explicable on the supposition that the artist had lived side by side with the extinct creature whose outlines he so accurately transferred to a fragment of one of its own tusks. The Esquimaux of the present day depict the animals living around them upon fragments of their own skeletons, and it appears to me that the men of the Post-glacial period, at which period we know that the Reindeer and the Mammoth flourished in southern Europe, only did the same. It is very improbable that a savage who had never seen a Mammoth could have elaborated it from his inner consciousness; he could merely have copied, as the Esquimaux do, such creatures as he was familiar with. I think we cannot avoid coming to the conclusion that, whatever may have been the age at which the sculptor of that animal lived, he was familiar with it; he used its ivory as one of the materials upon which to exercise his art; and we are consequently driven to the conclusion, that, however old or young man may be, he lived upon the earth at the time of these extinct animals. We next ask, in what shape does he personally present himself to us. We are told by the evolutionists that he was originally a monkey. This is not necessarily an

improbable fact; we must not scout the idea merely because we are apt to smile at it; we must look at the evidence upon which the hypothesis rests. There is no doubt whatever that man is constructed upon the same type as the monkey, and that when you put their skeletons side by side, though there are certain points of difference, there are greater and stronger points of resemblance. Consequently, *à priori*, assuming that the doctrine of evolution is true, it would be extremely probable that man had developed out of one of the larger and more man-like types of ape. If we merely study man's skeleton as a whole, I can obtain from it no evidence that necessarily upsets the conclusions of the evolutionists; but when we come to study certain special features, I think I see very grave difficulties. In the first place, when we examine the brain-pan of the monkey and compare it with that of man, I need scarcely say how large is the difference between the magnitude of the human brain and that o' the highest type of monkey that we are familiar with. Of course it is very difficult to decide how much these differences are worth. We sometimes find a man with a little brain made of superior material, who, mentally, surpasses another man with a bigger brain made of baser material. But let us see to what this comparison of brain-power brings us. The largest Gorilla has a brain of about thirty-four and a half inches of cubic capacity; but this magnitude is exceptional; generally speaking, the brain of the Gorilla has from thirty to thirty two inches of cubic capacity. The brain of the highest form of intellectual man has about 114 inches of cubic capacity. Between these two extremes there is an enormous difference. But the evolutionist properly says, "I have nothing to do with extremes; I have only to study the highest form of ape and the lowest form of man, to see if a link can be found uniting the two."

The smallest known adult human brain, respecting the accuracy of the measurements of which there exists no room for doubt, is one described by Professor Marshall of London. It is that of a Hottentot woman; we do not know her age or whether or not she was an idiot. When we find the brains of Englishmen and Europeans with a less cubic capacity than about sixty inches, we are told by Dr. Davis, one of our highest authorities on this subject, that they are invariably those of idiots; but it does not follow that this brain capacity would necessarily indicate idiocy in savages. The brain of the Hottentot woman measured sixty-two and a half cubic inches.

The evolutionists argue that since there is such a diversity in the brain of humanity, varying from 114 cubic inches to sixty-two, there is no reason why we should not go down to thirty inches and reach the level of the Gorilla. I contend that this is not a philosophical argument, and I will tell you why. Suppose you try to stretch a cord already three feet long, you may easily add some inches to its length; but having done this you will find it far more difficult to stretch it another inch than you did to stretch it the first half-dozen. You have reached the limit of its elasticity, and, use what effort you may, any further strain only snaps it in two. Apply this to the human brain. It is true there is an elasticity in the development of this organ that admits of its ranging between 62 and 114 inches, but because you have got so low as 62 inches it does not follow that it could be reduced in size to the extent of 28 inches more. I think this statement is sustained by archæological evidence. The two oldest human crania that have yet been found are those known as the Engis and Neanderthal skulls. Of these the former was unquestionably the more ancient. Yet Professor Huxley admits that it has probably a cubic capacity of 75 inches, and might have belonged either to a negro or to a philosopher. The Neanderthal specimen is much more imperfect, hence its exact capacity is not easily calculated; but it was probably much inferior to the Engis one, though its owner lived at a later period of time than was the case with the Engis savage. We thus see that the facts exhibited by the oldest known skull carries us far away from the Gorilla, and leave us solely dependent upon possibilities in attempting to build up our hypotheses. I am brought to the conclusion, that, so far as the skull is concerned, there is a wide gulf yet to be bridged over, deeper than the uncompromising advocates of evolution appear to recognise. But it is not to brain measurements, nor to any other merely structural peculiarities, that I am inclined to look for evidence bearing upon this problem—but to the psychological peculiarities which separate man from the most exalted of the lower creatures. The caves of the Dordogne reveal primæval man to us as an artist—rude, it is true, yet using his flint stones as graving tools, and sculpturing, with these imperfect implements, life-like representations of the creatures amongst which he lived. Now what have we in any Gorilla that prepares us for these manifestations of artistic talent? Literally nothing: yet this is only one of the in-

numerable mental and moral potentialities which separate man from the brute. It appears to me unphilosophical to say that these powers have been produced by the influence of man's surroundings acting upon his organisation. I would urge that all that those surroundings have effected has been, not to create, but to call into activity, powers that were already latent in man's nature. When we talk about what civilisation has gradually accomplished, we must remember that civilisation has proceeded from the exercise of qualities residing *within* man himself, and not from physical influences operating from *without*—hence civilisation, so far from being a product of the "surroundings" of Mr. Spencer, is merely a proof of the existence in man of latent potentialities, which no surroundings could create, however much they might aid in stimulating them into activity. As it is, there is no race of men so degraded that they cannot be taught in the course of a very few generations to display mental qualities to which the mere animal, however long he may have dwelt within the influence of civilised man, can lay no claim. Man can not only look backwards by an effort of memory, but anticipate the possible joys and sorrows of the future, which no animal can do. He can entertain abstract conceptions of good and evil, of beauty and its opposites, of right and wrong. He can work out the most intricate intellectual problems by processes even more intricate than the problems to be solved; and finally, when we regard man in the loftiest of his relations, we find him in possession of a sense of responsibility, not only to his fellow-men, but to the Supreme Ruler of the Universe; he has almost always some abstract conception, however vague, of a Being whom his eye hath not seen, but to whom his instincts tell him that he must one day render an account of his doings whilst on earth, and from whom he expects to receive a future life; a hope in which the most developed of brutes has no part.

WHY THE EARTH'S CHEMISTRY IS AS IT IS.

THREE LECTURES

BY J. NORMAN LOCKYER, ESQ., F.R.S.

LECTURE I.

In the three preceding lectures of this series, the chemical constitution of the Earth has been brought before you, and my part in the course, as I understand it, is to deal with the bodies, so far as we know them, which people space; in order that the earth's true place in nature, so far as its chemical and physical constitution is concerned, may be ascertained, and the reasons for that constitution inquired into.

For this purpose it is necessary that I should enter at some length into the constitution of those masses of matter which lie beyond the earth on which we dwell, and even beyond the system, and, it may be, the universe, of which we form a part. And you will naturally—some of you at least—ask, How is it possible that such knowledge as this has been attained? Prof. Roscoe, when he wished to tell you about the chemical composition of the earth's crust, was enabled to bring before you specimens of its different constituents, and could tell you how these specimens had been handled and weighed and experimented upon in different ways in his laboratory; but when we have to deal with the chemical constitution of bodies so

many millions of miles removed from us that we know as a matter of fact that the light which now enables us to see them must have left them hundreds of years ago, it is perfectly clear that such methods as those indicated by Dr. Roscoe are entirely powerless. In fact some other process is needed, with one exception. There are certain celestial messengers come to us from time to time which we can touch and which we can handle—I mean Meteorites, which appear to us as falling stars or aërolites; bright, beautiful objects, like those rockets which are going up to-night, and which, fortunately for science, last long enough to come down to the solid crust of the earth, where they cool and where we may subsequently examine them, as Dr. Roscoe has already told you. But with this exception, it is clear to you that ordinary chemical processes are entirely out of the question.

The progress of physical science has been in this wise:—As man has grown older the earth on which we dwell has dwindled down. It began as the centre of the universe; it has ended as a small mass of matter revolving round what probably is a small star—I mean the sun. But although the progress of science has been thus in a way to degrade the earth, I am sure you will think with me that man's intellect has been a distinct gainer by the process; for it is not too much to say that as the earth's place in nature has dwindled down, so has man's mental horizon been extended. That is very well shown by two fundamental considerations which I must bring before you in the first instance. In the year 1610, or thereabouts. that is to say, about two centuries and a half ago, thanks to the labours of men in Holland and in Italy, but chiefly to the genius of the immortal Galileo, the telescope was invented, and we got an untold addition to our mental wealth. The skies were peopled by means of the telescope, and the earth, which up to that time had been supposed the centre of everything, was put in its right place; bodies were observed shining millions and millions of miles away—bodies which up to that time had bathed the earth with light without any response from the human eye; and what was the result? Philosophers were enabled to class all the shining orbs of heaven into two great divisions—those bodies, namely, which shone like the sun with a light of their own, and those which shone by bórrowed light. The bodies which were found to shine by borrowed light and not by any light of their own were bodies which eventually were classed together

and termed the solar system—a family of planets which go round the sun, each in its proper path, each in its proper time; which are lighted up by the sun; which are warmed by the sun, and to the inhabitants of which the sun is the fountain of every kind of energy. We have from this classification the first great grouping of celestial bodies into those which shine by their own light, which, with the exception of the sun, are outside the solar system; and into those which shine by reflected light, which classification included all the bodies of the solar system except the sun. Now I will throw on the screen a diagram of the solar system, in order that you may exactly see which these bodies are, that reflect light, and in this case the light of the sun. I am very anxious indeed that you should understand the importance of this first classification, because the next one which I shall have to bring before you will go very much further into detail. We have, as representing the bodies of the solar system, first of all in the centre the Sun, which shines by its own light; and next, in the order of distance from it, Mercury, Venus, the Earth, Mars, a group of small planets called the Asteroids; then after them, Jupiter, Saturn, Uranus, and Neptune; Neptune being the last member of the solar family, so far as our knowledge at present goes.

When I call your attention to the next classification, I shall no longer have to refer to the illustrious Florentine, but to your own townsman, Professor Balfour Stewart, and to Professor Stokes. Their labours have given us another and more searching grouping, so to speak, by which we can go into much greater detail. This grouping is no longer based on the teachings of the telescope, but on the teachings of the spectroscope; and here, if you will allow me, I will state as briefly as may be the nature of this teaching, as you will find it of extreme importance, as we go along, to understand the terminology which I shall have to use. The important results to which we have arrived—thanks to the work of Stewart, Stokes, and others, and to the introduction of the spectroscope—can be shortly stated.

So long as Dr. Roscoe was telling you about taking a specimen of iron and analysing it, and taking a specimen of calcium and weighing it, and so on, it might not have been perfectly obvious to all of you that before you could recognise the existence of that calcium, and before you could see the beam of the scale go up or down, according to the precise weight of

it, a certain connection had been established between that calcium, let us say, and yourself—your consciousness. But when I shall have to tell of the chemical constitution of bodies thousands of millions of miles away, the necessity for some connection between our eyes—our consciousness—and those distant objects, will force itself upon us ; and it is important therefore at the threshold that we should refer to it. These distant bodies are visible to us by means of their unrest ; if all the bodies in space were absolutely tranquil we should never see them ; but the normal condition of everything in nature is a state of most beautiful and exquisite unrest. Scientific men call this a state of vibration ; but we need not quarrel about terms. Everything in nature, far or near, is in this state of unrest, and if it were not so there would be for us no external world. From every material substance, including these distant worlds, the vibrations of their smallest particles or of their largest masses come to us along a medium which scientific men call ether, not that they know all about it, but because it is necessary, in order that their work may go on at all, that they should assume that there is a something infinitely finer than matter, and not at all like the attenuated matter which pervades all space. This ether forms the highway along which the vibrations due to the state of unrest of matter travel to our eye, and afterwards to our brain, thus begetting in our consciousness the impression of the material world.

Here, then, we have a vibration of the most distant mass of matter in the universe communicated to our optic nerves by means of this ether. How comes it that any chemical knowledge can be acquired concerning these bodies? In this way. The spectroscope tells us that when we break a mass of matter down to its finest particles, or, as some people prefer to call them, ultimate molecules, the vibrations of these ultimate parts of each different kind of matter are absolutely distinct ; so that if I get the ultimate particle, say of calcium, and observe its vibrations by scientific means—what those scientific means are I shall show you by and by—we find that the kind of unrest of one substance—of the calcium, for instance—is different from the kind of unrest or mode of vibration—which is the same thing—of another substance, let us say sodium. Mark well that I say when we have brought these substances down to their ultimate or to almost their ultimate finenesses, because until we have done so the

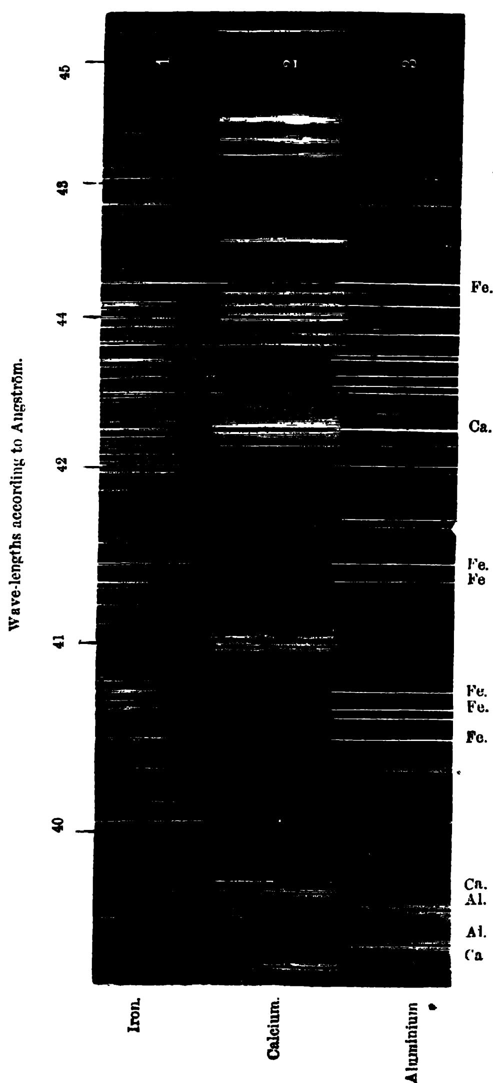


FIG. 1.—Comparison of the line spectra of Iron, Calcium, and Aluminium, with common impurities. Copy of a photograph by Lockyer, in which, by dividing the slit of the spectroscope into sections, and admitting light from the various light sources through them in succession, spectra of different elements are recorded on the same photographic plate.

vibrations of the larger molecular aggregations are absolutely powerless to tell us anything about their chemical nature, but they are full of teaching as to physical conditions.

Now we know that when we bring down a substance to its finest state and observe, by means of the prism, the vibrations it communicates to the ether, we find that using a slit in the spectroscope and making these vibrations paint different images of the slit, we get at once just as distinct a series of images of the slit for each substance as we would get a distinct sequence of notes if we were playing different tunes on a piano. I have here a photograph which has been produced by such vibrations. I hope first to show you on the screen what is called the line spectrum due to the smallest particles of calcium and aluminium; and if I am successful you will perfectly understand the meaning of the term line spectrum. Here are the lines by which the metal calcium is recognised when the vibrations of its finest particles are observed by means of the spectroscope. The two central lines give you also the vibrations due to aluminium. If you look to the other part of the screen you will think perhaps that you are dealing with a different order of phenomena altogether, and in that you will be perfectly justified. In truth we have here on the same screen not only the line spectra of calcium and of aluminium, but what is termed the channelled-space spectrum of carbon; that is to say, while the calcium and the aluminium have been driven down to their finest states of separation by dissociation, the carbon has not been driven down so low, and therefore we get a different kind of spectrum.

These vibrations having been rendered, I hope, intelligible by means of these drawings, this important consideration comes into play—that whenever any element finds itself in this state of fineness and therefore competent to give rise to these phenomena, it will give rise to them in different degrees according to certain conditions. The intensest form in which they may be brought before you is observed when we employ electricity. In a great many cases the vibrations may be rendered very intense by heat. The heat of a furnace or of gas will, for instance, in a great many cases, suffice to give us these phenomena; but to see them in all their magnificence, their most extreme cases, we want the highest possible temperatures, or better still, the most extreme electric energy. What we get is the vibration of these particles rendered visible

to our eye by the bright images of the slit or by their bright "lines."

But that is not the only means we have of studying these states of unrest. We can study them almost equally well if, instead of dealing with the radiation of light from the particles themselves, we interpose them between us and a light-source of more complicated molecular structure, and hotter or more violently excited than the particles themselves. From such a source the light would come to us absolutely complete, as it is coming to us now from that gas; that is to say, a perfectly complete gamut of waves of light, from extreme red to extreme violet. I say that when we deal with these particles between us and a light-source competent to give us a *continuous spectrum*, then we find that the functions of these molecules are still the same, but that their effect upon our retinas is different. They are not vibrating strongly enough to give us effectively light of their own, but they are eager to vibrate, and, being so, they are employed, so to speak, in absorbing the light which otherwise would come to our eyes. So that whether we observe the bright spectrum of calcium or any other metal, or the absorption spectrum, we get lines exactly in the same part of the chromatic gamut, with the difference that when we are dealing with radiation we get bright lines, and when dealing with absorption we get dark ones.

Now that being so, it will be perfectly clear to all of you that we have it in our power to enormously extend the inquiries started by Galileo. We need no longer be content with dividing the non-terrestrial bodies into those which shine by their own light and those which shine by reflected light, but we may make a classification of this kind. We have first of all those bodies which we can study by means of the radiation of their molecules, that is to say bodies in which the mere state of unrest, as I have ventured to call it, the mere giving out of light by the molecules of which these celestial masses consist, is the only thing in question. Then again, we have another class in which we deal not only with the radiation of the interior, but with the absorption of the molecules or particles by which each body is surrounded. Then we have, to come back to Galileo's classification somewhat, those bodies which we observe by means of light which they reflect to us. Then again there may be, and in fact there is, a class of bodies which, although they send their light to us by reflection, still make this light, so to speak, pay

a second toll on its passage, and it comes to us reflected and absorbed.

NEBULÆ AND COMETS.

When we examine into the various bodies which people the skies, we find that among those which can be studied by means of their radiation alone there are two of the very largest groups. I refer to nebulæ and comets. Let us first deal with the nebulæ. A very small telescope indeed is all that is requisite to see some of the most magnificent nebulæ in the heavens. I will throw on the screen Lord Rosse's drawing of the nebula of Orion; but before I do so I should like to show you how the spectroscopic addition to our knowledge has been secured. For this purpose I can show you a drawing of the eye end of the largest telescope in England at the present time, one belonging to a North-countryman, Mr. Newall, of Gateshead, and you will at once understand how the spectroscope has been used to aid the telescope to obtain these additions to our knowledge which I shall have to bring before you. Here is the eye-piece end of Mr. Newall's telescope, which, magnified in this way, is perhaps about life-size, the object-glass being some twenty-five inches in diameter, and the focal length thirty or thirty-one feet. At the eye-piece end of the telescope we have attached to it at the focus the spectroscope, with a number of prisms depending upon the amount of light which each heavenly body which has to be investigated gives out. In this drawing I have shown the greatest number of prisms which are used when it is a question of observing the sun; but, as you will readily understand, if instead of observing the light of the sun concentrated by this enormous instrument, it is a question of observing the nebulæ and some of the fainter stars, then, as there is always a loss of light by making it traverse through any great thickness of glass, the number of prisms is much reduced; so that you may say broadly that we have the greatest possible number of prisms for observing the sun, and the smallest possible number of prisms, say one or two, for observing the spectra of the nebulæ and the spectra of the fixed stars —at all events of the fainter ones. I propose, in dealing both with the nebulæ and with comets, first to refer to the telescopic appearance of these heavenly bodies and then

afterwards draw attention to the spectroscopic results which have followed.

The question of the chemical and physical constitution of the nebulæ is one perhaps of the most interesting in the whole range of astronomical science, and it has occupied the attention of our most illustrious astronomers. Having now before you the *modus operandi*, I will throw the drawing of the nebula, which

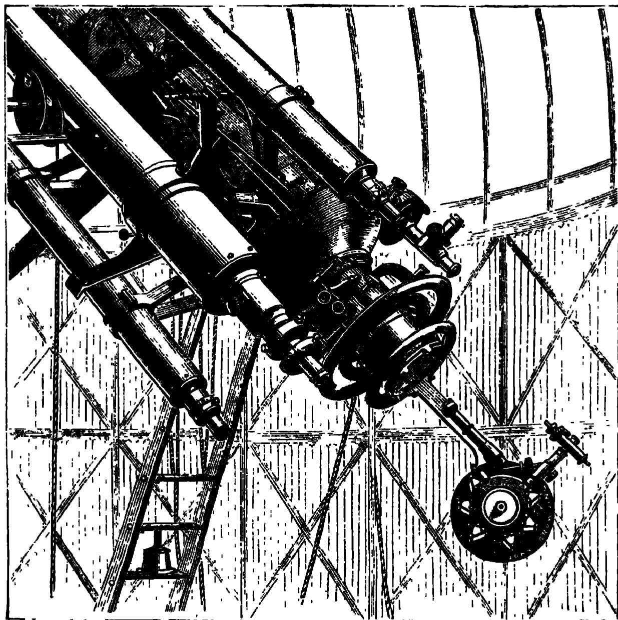


FIG. 2.—The eye-piece end of the Newall refractor (of 25 inches aperture) with spectroscope attached.

in these latitudes is most easily seen with the smallest instrument, and which, although it can be thus seen, is nevertheless one of the most magnificent objects in the whole heavens: I refer to the nebula of Orion. The first thing that strikes us about this nebula is its intense irregularity; there seems to be nothing celestial about it. Here and there we have great waves of light going along in diffuse courses from the central portion. Here

and there we have stars surrounded by a smaller nebulosity. Here again we have stars without any nebulosity at all; and look where we will, we see fleecy contortions and the most wondrous irregularity. Now it was not to be wondered at

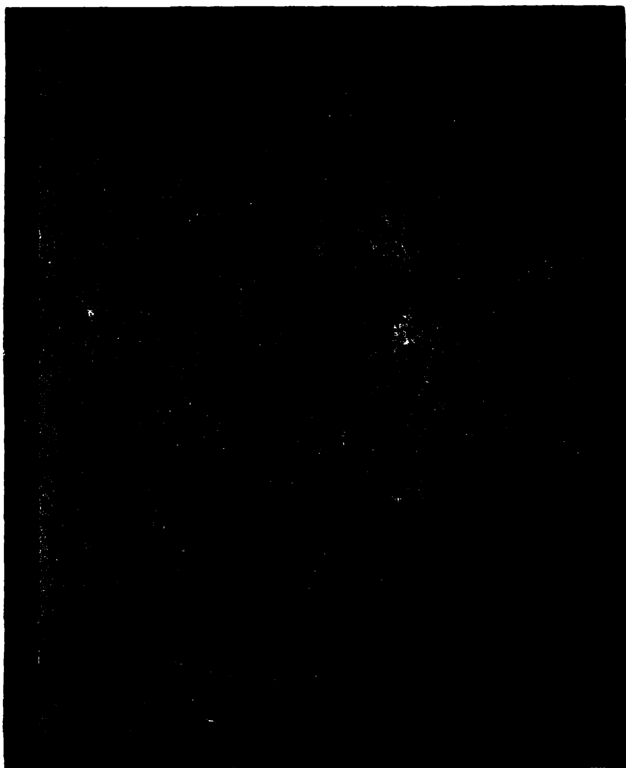


Fig 3 —Copy of Lord Rosse's drawing of the Nebula of Orion

that with the earliest telescopes the wildest guesses and the most profound thoughts were associated with these strange bodies. If we look at the works of Tycho Brahe and others. before the time of the astronomers of the last century. we find

them all occupied with an attempt at understanding the physics and the chemistry of these strange cosmical masses. Some were content to look upon them as fire dust; others saw in them enormous star clusters so infinitely removed that each element of the nebulosity might represent a single star, the single star being so far away, however, that, like the Milky Way, which we know to be composed of stars, to the naked eye the individuality of the stars did not come out. In the last century however, when Sir William Herschel with his wonderful perseverance at last had succeeded in eclipsing all former optical instruments by his magnificent forty-feet instru-



FIG. 4 —Nebula in process of condensation.

ment at Slough, then indeed the scientific study of nebulæ may be said to have commenced, and in a few years he had made lists of thousands of nebulæ; and his son, Sir John Herschel, later went to the Cape and added thousands more. Nearer our own time the magnificent instrument of Lord Rosse, at Parsonstown, has added to our knowledge, so that now the list of nebülæ is very considerable indeed. You will ask, Has the wonder connected with these strange objects been reduced by extended observations? I think I shall be able easily to show you that it has not been so reduced. Here, so far as form goes, we get a complete absence of all form—

absolute irregularity. Allow me to call your attention to some other drawings of nebulæ made by Lord Rosse, in which the irregularity typified by the nebula of Orion has given place to something absolutely different. Here we have an approximation to form and regularity, although the regularity is of different kinds. We have spiral nebulæ, annular nebulæ, and, as I may term them, *Saturnine* nebulæ. Note well the fact that the moment we leave the extreme irregularity of the nebula of Orion we always have to do with a condensation of some kind or other; in some cases with something between concentric and spiral convolutions round the central condensation.

Here is another series of nebulæ observed in the first instance by Sir John Herschel, which will intensify the classification to which I have referred. We have again spirals



FIG. 5.—Saturnine Nebula.

and double spirals. Finally, I will show you one of the most magnificent spiral nebulæ in the heavens from the same set of drawings. You see that the central condensation is fed, as it were, by spirals in all directions, some of them having condensations on the different branches. Now, Humboldt was not in possession of all these observations which I have been able to bring before you to-night, but he sums up in the first volume of his *Cosmos* these various forms of nebulæ in a very effective way. This summary will well repay perusal.

Now what are the modern ideas of the constitution of these strange bodies? I have already referred to the ideas of Tycho Brahe, Cassini, and the earlier observers. The work of the two Herschels left it as highly probable that these nebulæ

were really masses of cosmic dust, so to speak, or some kind of gaseous or vaporous material, which took these strange forms because there was nothing solid about them. But when Lord Rosse, with improved optical means, investigated some of the nebulæ which had been called irresolvable—a name given because no telescope up to that time was able to break them up into separate stars—he found that his telescope did break them up into distinct points of light, and then for a time in the pre-spectroscopic age, as one may call it, opinion swung round, and held that these nebulæ simply appeared as nebulæ not because they did not consist of stars, but because they were so far away that we could not see the separate stars of which they were composed. But not many years ago Dr. Huggins—to whom belongs the credit of having first turned the spectroscope



FIG. 6.—Nebula with rings.

on to the nebulæ—was enabled to show beyond all shadow of a doubt, that we had in the nebulæ something absolutely and completely distinct from stars. Dr. Huggins found, on turning his spectroscope upon several of these bodies, that the spectrum which he got from all of them was most characteristic. It was a bright line spectrum, and there was one line which was common to all of them In the lower part of the diagram the bright lines visible in the spectra of the different nebulæ are shown; and below, for purposes of reference, Dr. Huggins has shown the positions of various bright lines in the spectra given by other substances. There, for instance, in the blue-green, is the bright line due to hydrogen; there is another line in the green, due to magnesium; a line in the yellow due to sodium; and so on; and with these points of reference we

can easily determine the place in the spectrum of the three bright lines which Dr. Huggins found to be visible in the spectra of almost all the nebulæ examined; the differences between nebulæ and nebulæ, as I understand them, being indicated by the relative intensity of the lines, and the amount of continuous spectrum associated with them.

Having this enormous addition to our knowledge—the fact, namely, that the light given out by nebulæ is perfectly distinct from the light given out by stars—men of science were able to study the nature of nebulæ from a perfectly new standpoint.

One of the lines of the nebulæ is really coincident with a line of hydrogen, or, in other words, we have to deal with hydrogen gas when we are dealing with nebulæ. This has

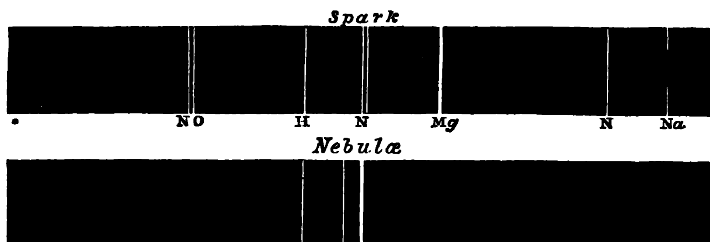


Fig. 7.—Spectrum of the Nebulæ (Huggins) compared with the bright lines certain elements.

been a most interesting and important point of departure. Dr. Huggins is of opinion that the nebulæ consist of masses of hydrogen gas; that there is nothing solid in the nebulæ, that it is a mere question of incandescent hydrogen, associated with something else, the chemical constitution of which has not yet been thoroughly established, because Dr. Huggins, with all his diligence, has not been able from his examination of the other chemical elements known, to get lines corresponding to those other two which we saw on the screen. But that is not the only view held as to the constitution of nebulæ. Sir William Thomson and Professor Tait consider it extremely probable that the nebulæ, instead of being masses of gas, may consist of clouds of stones. Now this at first seems so entirely at variance with the spectroscopic result that it is

not to be wondered at that the idea was at first considered to be somewhat *bizarre* and strange; but if one comes to think the matter out, one finds that there is a great deal of method in this strangeness, because Sir William Thomson and Professor Tait point out that if you had a cloud of stones, each one of which was in motion, and therefore liable to come into collision with some other stone now and then, you would get heat quite sufficient to render any circumambient gas incandescent; so that the phenomena of the spectroscope could be explained equally well on the assumption of a cloud of stones, providing always that you could at the same time show reasonable cause why these clouds of stones were "banging about" in an atmosphere of hydrogen. But nebulæ are not the only things in the universe which these distinguished Scotch professors imagine to be composed of clouds of stones. I think it is better therefore that I should postpone the further discussion of this point until we have become acquainted with the second class of bodies, which we study by means of their radiation—I refer to comets.

Comets.

Now when we pass from a nebula to a comet, it is clear that we come to a body of a perfectly different order in the celestial economy. Comets are distinguished from the nebulæ in many ways. The nebulæ, as a rule, are very far removed from us, so far that we have not the least idea of the distance of any one of them—we know that they are not within certain limits, and that they are also at rest apparently among the stars, while the comets are erratic bodies, which are now in our system, and now out of it; now close to us, and now infinitely removed in the depths of space.

Further, we know that the comets are not at all like the planets any more than they are like the nebulæ, because while our planets as a rule, excepting the smaller members or minor planets of the system, keep to one plane round the sun, called the plane of the ecliptic, which we may liken to a racecourse, round which all these planets pursue their revolutions—the comets do not keep to this plane, for they are as likely to dash into our system from above or below as they are to come into our system on the same plane as the planets. But more than this, while all the planets of our system are bound together by a motion which is always in the same direction

round the sun, when a comet comes into our system it is just as likely to go round the sun in an opposite direction. So that in the comets we have a complete differentiation between comet and nebula on the one hand, and comet and planet on the other.

I have here two or three general views which will give you a rough idea of the telescopic appearances of these strange visitors to our system. The peculiarity connected with comets generally is a double one—they have a bright head, and they have one or two or several appendages, called tails, which go from the head in a certain direction. There we have a comet with two tails—here with three; but these are not different comets; that is the comet which appeared in 1858, as seen at two different times. These views will give you a general idea of the appearance of comets, and of the way in which they travel among the stars. The physical interest of comets, which I shall have to call your attention to, is more intimately connected with the heads than with the tails; and I shall therefore hope to show you two or three more drawings, in which the heads of these comets will be in question. The characteristics of the heads are chiefly these—that in some cases we have to deal with what are called jets. The brightest point is called the nucleus of the comet, and the jets are so called because they seem to shoot out from the nucleus very much as the sparks shoot out of a squib.

Drawings of a comet, as seen at different times, show how these jets vary in appearance and direction. Instead of jets, some comets present phenomena of a very different character, called envelopes, which are thrown off concentrically from the nucleus. These envelopes are indicated in this drawing of a comet, made by Father Secchi in Rome. These then are the two physical peculiarities about the heads of comets; and you will see at once that we have something perfectly distinct from the nebulæ and the planets, and that one class of comets is at first sight different from another. The envelopes have been observed to rise from the nucleus with perfect and exquisite regularity in exactly the same way that the jets swing backwards and forwards. So much then for a very rough telescopic idea of the phenomena of comets.

What then says the spectroscope? I will now show you the diagram which I showed you before, in order to call your attention to another part of it. Formerly I called your attention to the spectrum of the nebulæ. I will now call your attention

to the spectrum of comets, and I am glad to have both the diagrams on the screen at the same time, because you will see that the spectroscopic difference is just as great as the telescopic difference. Now let me ask you to recall one of the first photographs I showed you—that of the carbon spectrum —and my definition of the channelled-space spectrum. You will at once recognise, I am sure, that here we have exactly that same kind of channelled-space spectrum that we had before. Side by side with this channelled-space spectrum.



Fig. 8—Concentric envelopes of Donati's Comet.

which is the spectrum of carbon, we have the spectrum of the comet, and you will see that the family likeness is very considerable, although it is true that the brightest portions of the spectrum of the comet are not absolutely coincident with the brightest portions of the spectrum of carbon which Mr. Huggins has drawn in the upper part of the diagram. What, then, is the meaning of this spectroscopic result? It is stated that if the spectroscope tells us anything, it tells us that we have to deal with carbon, or with hydro-carbon, as certainly in the case of comets, as we had to deal with hydrogen in the case of nebulæ. Here then we have a definite result with regard

to the brighter portions of the comets, that is to say, the nucleus, the envelopes, and the jets; but how about the tail? The same instrument, and the polariscope, when brought to bear on these longer appendages of comets, tell us that there we have perhaps no longer to deal with hydro carbon, certainly not with hydrocarbon in a state of considerable unrest, for we do not get the characteristic spectrum of hydro-carbon; we get apparently from the tails merely sun-light reflected. Are we then to say that comets are built up of hydro-carbon? No. Here again Professors Thomson and Tait come in and insist strangely enough that comets as well as nebulæ are masses of stones; that, in short, a comet is a bit of a nebula,

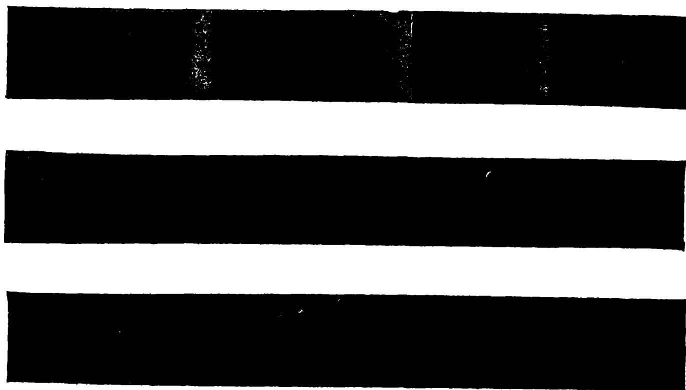


FIG. 9.—Cometary spectrum (Huggins).

differing from a nebula in this, that it is in violent motion as a whole, while the nebula is apparently at rest as a whole. You will find in *Good Words* of a few months ago an important article by Professor Tait, in which he goes into this question at very great length. He shows that if we have in the head of a comet a mass of stones, like a swarm of bees, banging about, and, at the same time, moving in an orbit around the sun, or it may be in its long path from the centre of our system to the centre of another system, and the stones colliding, you will get heat, and some gas will be evolved; some members of the mass will be quickened, while other constituents of the mass will be retarded in their motion, and

that in this way you have a probably sufficient explanation of the various forms which the telescope has revealed to us. And then finally he goes on to show that the result of these collisions would be such a smashing up of the constituents of the swarm that much finely-attenuated material would be left behind, sufficient to reflect sunlight, and to give rise to the phenomena of the tail.

Now, curiously enough while these ideas have been evolving themselves, a distinguished Italian astronomer, Schiaparelli, had also arrived at the conclusion that comets were closely connected with swarms of meteors; and he arrived at this conclusion by an examination of the paths of the meteors and the paths of certain comets. Astronomers now know exactly when to look out for what they call a meteor-swarm, or a mass of shooting-stars. They know, for instance, that on the night of the 20th of April they will most probably see shooting-stars coming from the constellation Lyra, and these shooting-stars they call the Lyriad shower. They know also that on the 10th and 11th of August they will see other shooting-stars, this time coming from the constellation Perseus. These also they call the Perseids. On Nov. 13 and 14 the Leonids may be expected, that is to say, that then is the time to look out for shooting stars which come from the constellation Leo. Now if astronomers can tell you that on a certain night—that is to say, when the earth is in a certain position in its orbit—shooting-stars will appear to come from a certain part of the heavens, namely, some particular constellation, it is because they have become acquainted with the path of those meteors round the sun. They have, in fact been able to get a very concrete idea of the orbits of those meteors, in the same way that we have a concrete idea of the orbit of the earth round the sun. They can tell exactly where and when they cut the plane of the ecliptic, and other things which I need not bring before you in detail. After comets have appeared two or three times, astronomers can also form an equally definite idea of their orbit round the sun. Now, what Schiaparelli did was this—he compared the orbits of these meteoric swarms with those of some of the comets, and he found some of them identical. For instance, in the case of the shower of April 20th in each year he found that there was a comet observed carefully in 1861 with absolutely the same path; for those shooting-stars which radiate from the constellation Perseus on 10th August he found that a comet observed in 1862 had exactly

the same path; for the Leonids, which appear on 13th and 14th November, he found that a comet, observed and calculated out accurately in the year 1866, had exactly the same path. And

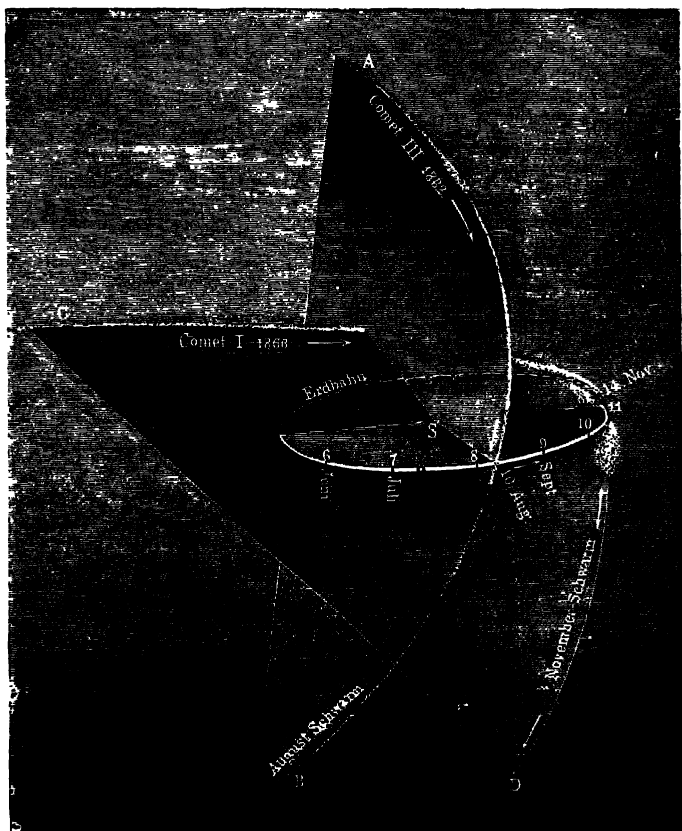


FIG. 10.—Diagram showing the paths of Comet I, 1866, and III., 1862, and their accompanying meteor swarms, and the points at which they cut the earth's path.

then with regard to the other principal group observed on the 27th and 28th November, he found that the falling stars seen in the constellation Andromeda on those nights had

exactly the orbit as a very well-calculated and most remarkable comet named after Biela the astronomer. Now, of course this suggestion of Schiaparelli gave an enormously increased interest to the investigation both of comets and meteors, and when the question was thoroughly gone into it was impossible to avoid the conclusion that when we have a shower of falling-stars we practically are going through part of a comet; and that when we see a comet in the sky we actually are seeing the behaviour of a swarm of meteors at a distance.

I hope to commence my next lecture by referring to some other considerations with regard to these meteorites, and then to call your attention to some experiments which suggest that the connection between meteors or falling-stars, comets and nebulæ, is of the very closest description.

WHY THE EARTH'S CHEMISTRY IS AS IT IS.

LECTURE II.

In the latter part of the last Lecture I referred to the chemical constitution of comets, so far as the spectroscope enables us to determine this constitution; and I endeavoured to point out to you what the telescope had revealed to us with reference to their physical constitution. I also again dwelt on one of the great triumphs of modern astronomy—namely, the discovery by Schiaparelli of the intimate connection between falling stars and comets.

Meteorites.

Now, from the falling star to the meteorite is a step so small that nothing need be said about it by me to-night. The difference between a falling star and a meteorite is simply this—that a falling star is a small mass of matter which is entirely burnt up in its passage through the higher regions of our air, whereas the meteorite is a falling star big enough to give us some residuum after the energetic action of heat has worked its will upon it in passing through the atmosphere. Observations of the rapidity with which falling stars and meteorites traverse our atmosphere have shown beyond a doubt that a meteorite could travel, say from Manchester to London, in as many seconds as an express train takes hours. You may imagine, therefore, that owing to this very rapid motion through a medium—and a medium constantly increasing in density—such as our air, that a considerable resistance is offered to the passage of the meteorite. This arrested motion in process of time becomes developed into what we call heat, and as a result in all cases we get

luminous effects, with this difference, that, whereas in the case of the falling star, the luminous effect is the only thing we get, in other cases we get in addition to it the actual descent of what we may term a celestial messenger from the depths of space. Of course, having these meteorites—these larger masses—falling to the earth, so that we can handle them, a great deal has been learned about their chemical and physical constitution, as Dr. Roscoe has already told you. I need not dwell at any great length upon this, after what Dr. Roscoe has said; but I may state that, generically, these celestial messengers may be divided into four groups. We have those which are almost entirely metallic. We have those which are almost entirely stony. We have those in which the metallic and the stony constituents are mixed in various proportions; and in a fourth, or last class, in addition to the materials to which I have already referred, there are to be found various combinations of hydrogen with carbon, termed hydro-carbons.

We have, therefore, in the language of the meteoric chemist, siderites, those which contain iron; aërolites, those which are chiefly stony; siderolites, which are mixed, half stony, half iron and nickel; and then again the carbonaceous group. Coming from this generic chemical grouping, a word may be said as to their appearance. And here, if you will read (for I cannot go into this question in any great detail) the writings of Maskelyne and Sorby, you will become acquainted with some most extraordinary facts and coincidences. Some of the meteorites are stated to exactly resemble volcanic bombs; others resemble volcanic tufa; others again bear evidence of having being subjected to actions which we know nothing whatever about in this earth of ours. Mr. Sorby, for instance, has gone so far, and I have no doubt perfectly justifiably, as to state that in some meteorites which he has examined microscopically there is evidence to show that they were formed in a region where, so to speak, there was no gravity; that is to say, far away from the surface of any such body as the sun or our earth. When we come to the actual chemical elements which these meteorites contain, we find ourselves in a region where knowledge is extremely rich, compared to what it is at present in the case of nebulæ and comets. It is anticipating matters somewhat, but it is worth while to state that the complete list of the metallic elements of meteorites is almost identical with the complete list of metals in this list

(Table of Elements contained in the Sun, page 136). It is more than a coincidence, I think, that the chief metallic constituents of meteorites are almost identical with the chief metallic constituents of the sun. But strange to say, this is by no means the case when we come to leave on one side the metallic elements and come to the metalloidal ones, such as carbon, and sulphur. Up to the present moment there is no published observation of the existence of any metalloid whatever in the sun's atmosphere. That does not say they do not exist; but at present we know nothing definite as to their existence.

Given these meteorites, and assuming them to be the meteoric swarm which Schiaparelli postulates for the comets —that is to say, supposing that we see first in the heavens a body which we call a comet, observe it with the spectroscope, and get from it the spectrum of hydro-carbon; and then suppose that subsequently this very same body, consisting, according to hypothesis, of a swarm of meteorites, comes into our air and gives us the appearance of falling stars, and probably also the occurrence of a fall of a meteorite or two, —what would most probably be the source of the luminosity? As a matter of fact what we do see when these bodies enter our atmosphere and are rendered incandescent by arrested motion, in the manner which I have already referred to, are spectroscopic indications of the existence of sodium. The bright yellow of a falling star is due to incandescent sodium vapour, sodium being that among the elements of all meteorites which is most volatile as a metal. Next after that, in the cases where brilliancy is extreme, and where the yellow colour of the falling star gives place to brilliant white or even to a dazzling bluish white, we get added to sodium indications of magnesium. And after that, in the case of falling stars brighter even than those which I have already supposed, we have added to the sodium and the magnesium unmistakable traces of iron vapour. Now this shows us very distinctly that if—I say if—according to this hypothesis, we really do get as falling stars what we get as the head of a comet, the temperature of a comet is much less than the temperature of the falling star while it is passing through our atmosphere, because in the comet we only get a temperature high enough to render the most volatile constituent, hydro carbon, incandescent, whereas we have passed that stage altogether when the meteorite comes into our atmosphere and the incandescence of hydro-carbon is replaced

by the incandescence of magnesium, sodium, and iron vapours. There is, therefore, abundant proof on this hypothesis that the temperature of a falling star, when it is passing through our air, is higher than the temperature of that same mass of matter when it formed part of the head of a comet.

There is one point to which I think I may be permitted to draw your attention, although at present it rests merely upon an unendorsed observation of my own. I thought it would be worth while to try what would happen if I enclosed specimens of meteorites, taken at random, in a tube from which I subsequently exhausted the air by a pump. After the pumping had gone on for some considerable time, of course we got an approach to a vacuum; and arrangements were made by means of which an electric spark could pass along this apparent vacuum, and give us the spectra of the gases evolved from the meteorites. Taking those precautions which are generally supposed to give us a spark of low temperature, and passing the current, we got a luminous effect which, on being analysed by the spectroscope gave us that same spectrum of hydro-carbon which Mr. Huggins, Donati, and others have made us perfectly familiar with as the spectrum of the head of a comet. There then we get the atmosphere of meteorites, not necessarily carbonaceous meteorites, but meteorites taken at random; and this atmosphere is exactly what we get in the head of a comet.

Now let me go one step further; and to take that step with advantage, allow me to refer to another point noticed in the last lecture, which was this—that whereas Schiaparelli had connected meteorites and falling stars with comets, Professors Tait and Thomson, on the other hand, had connected comets with nebulæ, both of them being, according to those physicists, clouds of stones. Now how was one to carry these spectroscopic observations into the region of the nebulæ? A Leyden jar was included in the circuit, and we had what is generally supposed to be an electric current giving us a very much higher temperature than we had before. What then was the spectrum? The spectrum, so far as the known lines were concerned, was the spectrum which we get from the nebulæ; for the hydro-carbon spectrum, which we get from the atmospheric meteorites at a low temperature, was replaced by the spectrum of hydrogen; the spectrum of hydrogen coming of course from the decomposition of the hydro-carbon, with the curious but at present unexplained fact that we got the spectrum indications

of hydrogen without indications of carbon. In my laboratory work I have come across other curious cases in which compound vapours when dissociated only gave us one spectrum at a time—by which I mean that in a vapour consisting of two well-known substances, under one condition we only get the spectrum of one substance, and under another condition we get the spectrum of the other substance alone, so in others again of both combined. The evidence seems therefore—though I do not profess to speak with certainty—entirely in favour of the ideas of Sir William Thomson and Professor Tait on the one hand, and of Schiaparelli on the other. I note this because I shall have again to refer to the conclusion to be drawn from it, namely, that there is probably an intimate connection between nebulæ, comets, meteorites, and falling stars.

The Stars.

Concluding what I have to say with regard to the first great group of the heavenly bodies, namely, that group which we can study by means of the radiation of light apart from absorption, I will now take up the next class, consisting of those bodies which we study by absorption.

What do I mean when I say those bodies which we study by absorption? I mean this—that whereas in the case of the radiation of light the vibrating molecules directly communicate with us and set in motion the ether which ultimately comes to our eyes; in absorbing bodies, on the other hand, the vibrations which we study have been set in motion not directly, but by the intrinsic vibration of other bodies further from us and more violently agitated than the vapours themselves, In other words, if you assume a mass of matter which is competent to give you every wave length of the spectrum—that is to say, a continuous spectrum, and if you assume around it individualised vapours at a lower temperature, those vapours, although they cannot be studied by their radiation, if they are not hot enough to allow their lines to be seen as bright lines on the bright background of the continuous spectrum, can still be studied by their absorption, because they are made to vibrate by those wave lengths given off by the interior mass passing through them with which they can synchronise. Therefore we pass from those celestial objects which we study by

means of their bright lines, to those other bodies which we study by their dark lines; we pass from radiation spectra to absorption spectra.

What bodies in the skies then can we get at by this means? We have already, by means of radiation, been able to gather several secrets from nebulæ and from comets, which are the objects which we can study by means of their radiation alone. The most numerous class of bodies in the universe, so far at

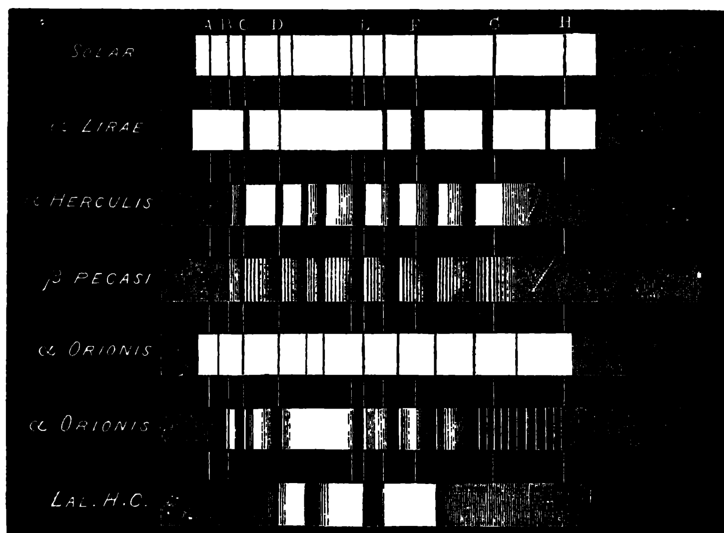


FIG. 11.—Various types of stellar spectra.

all events as we are able to grasp the universe, are what we term the fixed stars, including, of course, our sun.

In order to make my meaning quite clear, I will throw upon the screen a drawing which we owe to Father Secchi, which will give you at one view several typical spectra of the fixed stars. When we pass from the nebulæ and the comets we pass from bodies which have almost identical spectra in each case to bodies in which the spectra are very different. This diagram shows us the different classes into which the series may be grouped the moment we put this spectroscopic question

to them: What lines have you in your spectrum? or What channelled spaces have you in your spectrum? We have at the top, you see, the spectrum against which is written the word "solar;" and that means that we have there in our sun a representation of a large number of stars, which, be it also remarked, may be large or small, for this classification apparently does not hold good for the different magnitudes.

Then, again, we have a spectrum which is common to a great number of the most brilliant stars in the heavens; and the difference between that spectrum and the upper one is that it has a much smaller number of lines, and that these lines are thicker. Another spectrum is somewhat like the solar spec-

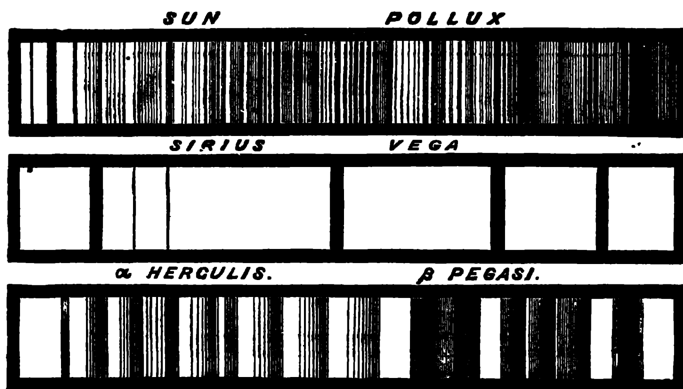


FIG. 12.—The three chief types of spectra seen in more detail.

trum, so far as the number of lines is concerned, but some of the lines do not agree in position with the lines in the solar spectrum. Now, in the three spectra to which I have already called your attention you see that we have unmistakable line-absorption; and, in the light of what I ventured to bring before you in the last lecture, I hope you will quite understand that we have evidences in the atmospheres of those stars that the elements are broken down to their ultimate degree of fineness. But when I call your attention to the other four stellar groups, you will find it is no longer a question of line-absorption; instead, indeed, of a spectrum, resembling the spectrum of calcium and iron, which I showed

you in the last lecture, we have now most distinct channelled spectra, which will remind you of that beautiful photograph of carbon. That carbon vapour we know was more complicated than the calcium vapour and iron vapour with which it was mixed. We have then, so far as this diagram can show us, different kinds of absorption going on in the stars; so much so, that we can divide the stars into groups, first, according to whether or not their absorption is the line-absorption or the channelled-space absorption; and then, again, according to whether the absorption is indicated to us by many thin lines or by few thick ones. I have another diagram here which will enable us to go somewhat more into detail. This diagram we also owe to Father Secchi. It

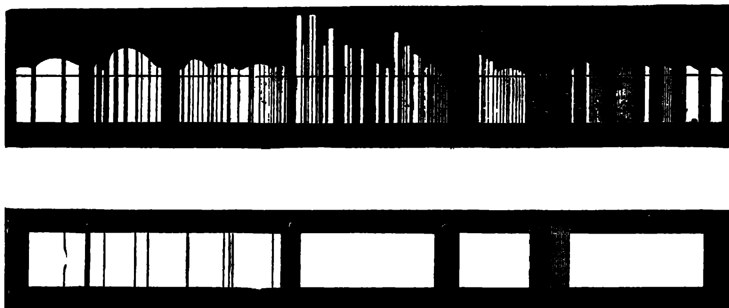


FIG. 13.—Spectrum of α Orionis compared with that of Sirius.

shows you with what extreme care this kind of observation has already been commenced and what detail has already been acquired. We have in the upper part a drawing of the spectrum of α Orionis from which you will gather that the first drawing which I brought to your notice was only intended to give you the generic differences between the star classes, and not the special differences. Difference between a star of the type of the sun and of a star of the type of Sirius becomes much more clear and definite when we have the opportunity of observing the enormous number of lines in the stars of the sun type and the comparative freedom from lines of the stars like Sirius and Vega. In order to enter still further into detail in the case of the nearest star, I

will throw on the screen a photograph of a large part of the solar spectrum, which we owe to Mr. Rutherfurd of New York. This will indicate to you the extreme importance of getting the sun to do as much work for us as it can in the way of recording its own chemical constitution by means of photography. This photograph is on such a scale that in order to include a small portion of the spectrum it has been necessary to give it in five successive strips, the less refrangible lines being to the left at the top, and the most refrangible to the right at the bottom. Now, the chemical constitution of the sun and stars, so far as the detail is concerned, consists in finding out, as I am sure you all know, to the absorption of what particular element each of these lines is due. Now there, for instance, in the line F, we know that we have to do with hydrogen. We know that in the line near

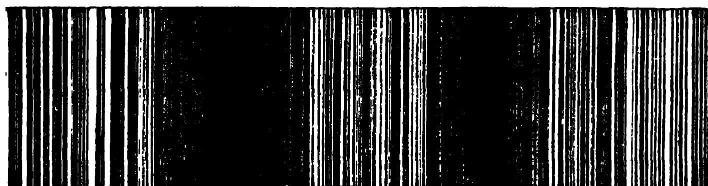


FIG. 14.—Copy of a photograph of the solar spectrum in the region of the thick calcium lines, by Lockyer.

G we have to deal with hydrogen again, and that a great many of these very complex lines about G are due some of them to iron, some to calcium, and some to strontium, and so on. Coming to the extreme limit of the visible spectrum. we find lines thicker than all the rest, and those lines we know to be due to calcium. The reason those lines are apparently thicker than all the rest seems to be that probably there is more calcium than anything else in that particular part of the sun's atmosphere where this absorption takes place.

Now that remark opens up the kind of inquiry which is possible to us when we wish to inquire into the chemical constitution of the stars. We have the position of the lines, the number of lines, and the thickness of the lines; and, let me add, when we get definite evidence of change, we want to know the change in the thickness of the lines. Now, when

we come to deal with the first class of stars, the brightest and the bluest in the heavens—stars such as Sirius and Vega—much brighter and probably therefore hotter than our own sun—we deal with the extremest simplicity of chemical constitution. We seem to be dealing almost entirely with hydrogen alone. I say almost entirely, because there appear in the best instruments traces of sodium and magnesium—those metals we have already been familiarised with by our reference to meteorites—in addition to the hydrogen; but that simplicity of construction of the spectrum which you saw on the screen, and the thickness of the lines, taken in connection with the position of those lines, indicates to us that the atmospheres of those stars are composed to very great extent of hydrogen.

When we pass to the stars of the second class, such as our sun, the chemical complexity is very much greater. If we take the sun as a type of stars of the second class, many of the elements present in its atmosphere have been determined with almost absolute certainty:—

TABLE OF ELEMENTS IN THE SUN.

Coronal Atmosphere	1474 stuff (new element ?) Hydrogen, sub-incandescent.
Chromosphere . . .	Hydrogen, incandescent Helium (new element ?) Calcium Magnesium.
Spot Zone	Sodium Titanium Chromium ? Aluminium.
Reversing Layer .	Iron Manganese Cobalt Nickel Copper Zinc Potassium Strontium Barium Cadmium Lead.

Besides which there are indications that other metals may soon be added to the list, vanadium for instance. The stars then

of the second class, of which our sun is one, have atmospheres composed of these elements. Here, as in the case of the meteorites, our knowledge is already great and is rapidly increasing; but when we come to the red stars, to the stars which give us channelled-space absorption, there up to the present time our knowledge has been extremely limited. We have not been able to study the molecules of elementary bodies and compound bodies under those conditions at which they give us the channelled-space spectra to such an extent as we have been able to study them under those conditions at which they give us line-spectra. The result is therefore that when we come to the third class of stars with these channelled spaces, science at the present moment recoils, and is compelled to say that she does not know of what the atmospheres of these stars is composed. But again, in the light of the photograph which I showed you in my last lecture, we can come to certain very definite ideas. For instance, we have no difficulty in coming to the conclusion that the star in which we get the channelled-space absorption must be cooler than the star in which the absorption is of the line kind. It is not at all impossible that science, by taking an entire survey of the whole of space, may, in not a very long period, be in possession of such facts as apparently she could only have acquired by having been present in all points of time; we may get, in fact, from different regions of space, conditions which have happened to the same body at different epochs of time; and already it is not, I think, too much to suggest that when we get a star with a channelled space absorption we have got a cooling star, the absorption of which must once have been of the line kind; therefore the stars which now give us line-absorption as they get cooler must give us channelled space spectra, and so on till they become dim and cease to give us light altogether.

All of you, I am sure, have been struck, one night or another in your lives, with the exquisite colours of some stars. There is no sameness in Nature. The colours of the stars are not so well seen in Manchester or in England generally as they are in the tropics and in more favoured lands; but still we do, if we take the trouble, easily see evidences of the most beautiful coloration amongst these celestial bodies. Nor is this all. More careful observations of the stars make it absolutely clear to us that they vary very much in the light which they give out; and it is also known that the variation

of colour may go on *pari passu* with the variation of their light. We owe the first important suggestion on this point to Angström. who showed that if in the atmosphere of a star we imagine the molecules at what we may term the critical point, and suppose them to be in a condition of heat which enabled them to give the line spectrum, and also near that reduced temperature and possible association at which they could give the channelled space absorption, a very small reduction of temperature would at once change utterly the amount of light given out by that star. For instance, if you assume that stars of the third class were once stars of the second, we know that if the change could have taken place suddenly, it would have appeared as if these stars lost a great deal of their light, and that the yellow light was gradually changed to red. Now the variability of stars can go to such an extent, as I have already hinted, that a star will go out altogether, so far as our powers of seeing it are concerned. And again we may perceive a star in a region of the heavens where a night before no brilliancy was visible. How can we account for this? So far as the physics of the stars are concerned, the merely chemical considerations would at once explain to you how it was that a star should by and by lose its light. The cooling of the atmosphere, and the consequent increased absorption of the molecules of that atmosphere, as they got more complicated by the reduction of temperature, would be quite sufficient to stop all light which came from the nucleus. When we inquire how it comes that a star may suddenly shine out where no star ever shone before, there the law of uniformity, the law of continuity, does not come to our rescue so well as it does in the first case. We do want there something like a catastrophe. You recollect that a few years ago Dr. Huggins was enabled to make a most important series of observations on a star which broke suddenly into intense light and then faded away into the utmost bounds of visibility. Now there it was found that the light of the star, changing as it did, gave rise to perfectly different spectrum effects. That star when it was only of a certain definite brightness, as it was at first seen, gave us a spectrum with dark lines similar to those I have thrown on the screen; but when its maximum brilliancy was reached, the character of the spectrum changed—a spectrum of bright lines was added; and then we had an indication of a new class of bodies, namely, those bodies which we study both by their radiation and absorption. So much for the facts.

THE SUN.

We will now pass to the sun, so that we may be able to build any conclusions with regard to the causes of these phenomena in the case of the more distant bodies on somewhat firmer foundations than we could have done had we not this big star close to us to refer to. In the first place, I would like to show you that the statements which have been made with regard to the chemical constitution of the stars rest upon a basis sufficiently firm to justify me in bringing them before you. Dr. Huggins, who was the first to observe the spectra of the stars in a manner which left nothing to be desired, so far as eye observations were concerned, made comparisons of the dark lines of the stars with the bright lines of the different elements in the same instrument at the same moment. A very small addition to that method, namely, the introduction of photography, enables us not only to do this, but to make a record which is good for all time. I propose therefore to illustrate the method by throwing upon the screen two photographic comparisons, the object of which was to determine which were the lines I have already shown you in the solar spectrum, which were really due to the vibration of the particles of iron vapour in the atmosphere of the sun. For that purpose all that one had to do was first to photograph the spectrum of the sun, and then on the same plate and by the same instrument, under absolutely the same conditions, photograph the spectrum given by the iron vapour. You will see the result on the screen. Of course such a photograph has to be made for every chemical element the existence of which in the sun we wish to study. I may remark, in passing, that the only difficulty in illustrating this kind of inquiry is the impossibility one labours under of ever getting a chemical substance which is absolutely pure. We have now on the screen, on a very large scale indeed, that part of the solar spectrum which in Mr. Rutherfurd's photograph was to the extreme right at bottom. Here are the two calcium lines which you saw before, and which are much thicker than any other lines in the spectrum. The dark lines are the regions where there is no light to paint the image of the slit in consequence of that light having been absorbed by the iron vapour in the atmosphere of the sun; and above these dark lines you have the images of the slit painted by

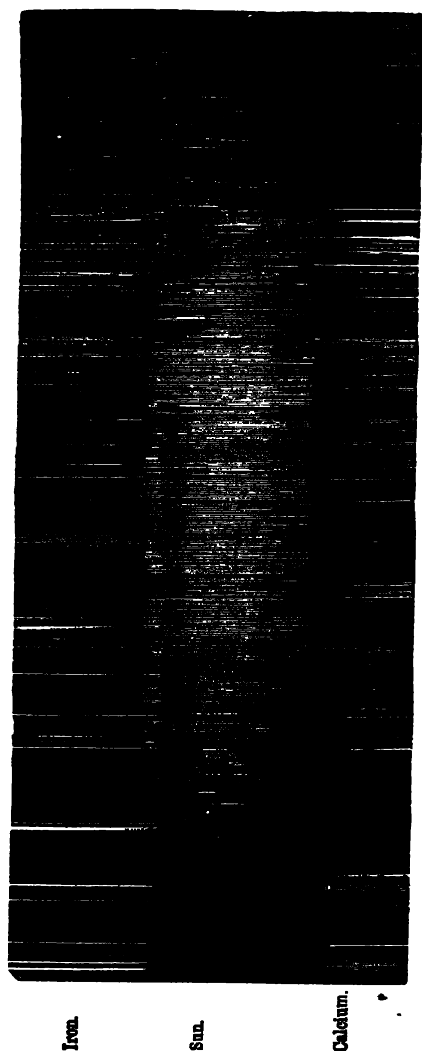


FIG. 15.—Comparison of the absorption spectrum of the Sun with the radiation spectra of iron and calcium, with common impurities. Copy of a photograph by Lockyer.

the vibrations of iron vapour, not in the sun's atmosphere, but in a laboratory at South Kensington. If you will take the trouble to compare the more definite lines you will see that there is a perfect coincidence between the bright lines and the dark ones which are caused by the iron vapour of the sun.

The next diagram[1] is, if anything, more interesting still. In this one we are dealing not with iron but with manganese. We have, you see, bright lines coincident with the dark lines of calcium, but these are due to calcium impurities. I am anxious to call your attention to a group of four lines in the solar spectrum and a broad band of light, corresponding with these in the spectrum of manganese. There are three bands of absorption on this band exactly coinciding with the three more refrangible lines in the solar spectrum to which I have drawn attention; that is to say, we not only in that photograph get absolute proof that those four lines in the solar spectrum are due to absorption at the sun by vapour of manganese, but we get the vapour of manganese in a laboratory doing for the more incandescent manganese what the outside sun does for the inside sun; we have in fact the cool vapour of manganese around the incandescent manganese giving us *nearly* the same absorptive effects as the manganese vapour does at the sun.

So much then for the method of acquiring these chemical facts. If we merely had that method, we should be able to say that certain substances exist in the sun; but that would scarcely be enough. We don't want to know merely that such and such substances exist in the sun or in a distant star; if possible, we want to know whereabouts in that star the particular substance lies. Now for that purpose we have to consider these spectroscopic results in connection with the telescopic results. What I mean by telescopic results will be brought before you by throwing on the screen in the first place a photograph of the sun which again I owe to the kindness of Mr. Rutherfurd of New York. Here is the sun on an enormous scale, photographed by itself.

THE CHEMISTRY OF DIFFERENT PORTIONS OF THE SUN.

Now if instead of observing the sun as ordinarily visible, we observe it during an eclipse, we find that the sun that we see is only the small interior nucleus, so to speak, of the true sun,

[1] This photograph is not given, but the same effect may be noticed in Fig. 1 in the case of the thicker lines of calcium and aluminium.

and the reason we see the interior nucleus alone is because it is so very much more bright than the surrounding atmosphere. This photograph (Fig. 16) was taken in India in 1871. When we get the dark moon exactly between us and the brighter interior sun, there is no difficulty whatever in seeing that there is an atmosphere with its own characteristic effects, extending to a considerable distance above what we consider the sun ordinarily speaking (Fig. 17). So that you see telescopically we can make a complete distinction between one part of the sun and the other.

Now the question is, can we spectroscopically determine in what particular part of the sun each of these elements exists?

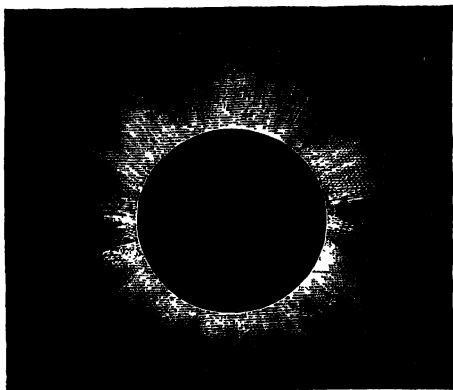


FIG. 16.—The Sun's corona, from a photograph taken in 1871.

Here is another drawing, which shows you what happens when we observe the region intermediate between the two I have shown you. The first drawing brought before you the photosphere of the sun; the second drawing brought before you the corona—the name given to all the exterior of the sun. At the base of the coronal atmosphere, that is, just above the photosphere, we have a region which has been named the chromosphere, in which certain strange forms are to be seen, and which are here shown (Fig. 18) from a drawing by Professor Young. These have been called "prominences," or "red flames."

So that we have the photosphere underlying part of the sun's

atmosphere and above all the coronal atmosphere; resting in the middle, so to speak, this chromosphere and its prominences; and then between the photosphere and the base of the chromo-

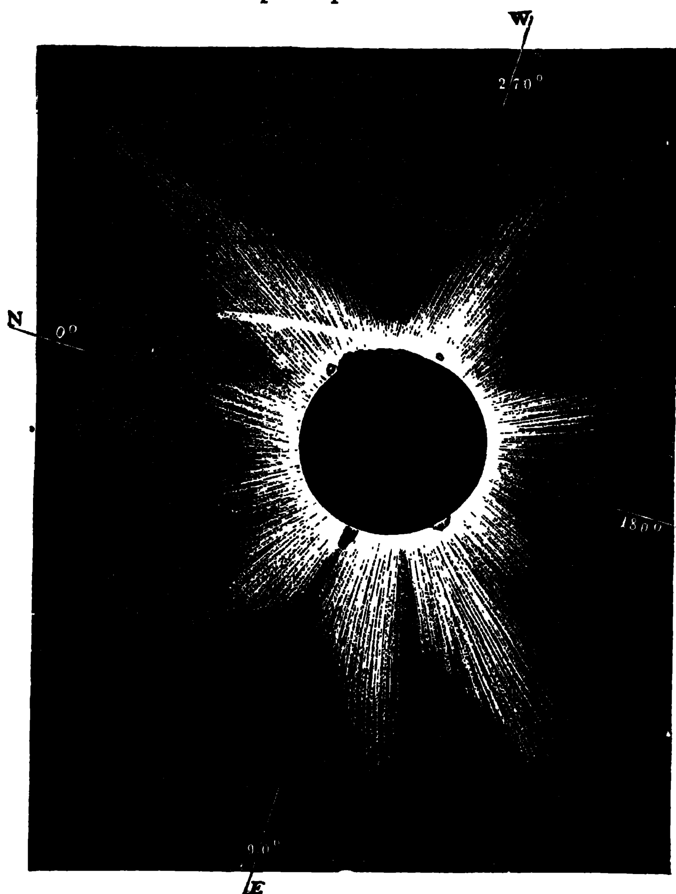


FIG. 17.—The Sun's corona and prominences, sketched during the eclipse of 1868.

sphere an extremely thin layer where most of the absorption takes place. Now this thin layer has been called the reversing layer, because it is here that the sun's light is reversed and

the Fraunhofer lines produced; so that the statements generally made as to the chemical constitution of the sun and stars really refer to this particular film—for film it is, in comparison to the size of the sun—lying between the chromosphere and photosphere. We have, therefore, the photosphere, reversing layer, chromosphere and coronal atmosphere, into which, if we can, we may sort out the different elements.

Now this is what has been done, and the results are shown in the table (page 136).

If you imagine an arrow shot into the sun, it would first pass through the unknown element of which the upper part

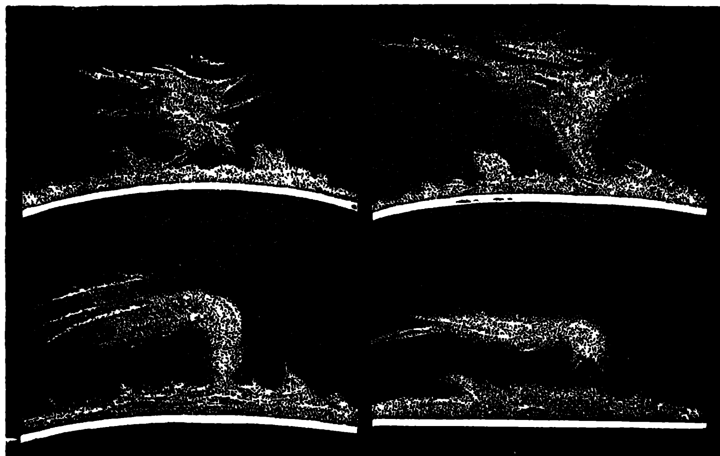


Fig. 18.—Young's drawings of prominences.

of the coronal atmosphere seems to be chiefly composed; it would then come to the region where practically there is hydrogen and nothing else; getting into the chromosphere you come to another new element, and then in the reversing layer you get magnesium, calcium, sodium, &c. At length we come to traces of some substances which either exist there in very small quantities or lie at a much lower level than the others.

For one of the important teachings of this work seems to be that at the great temperature of the sun—a temperature which brings about a dissociation much more complete than

anything we can obtain here even by electricity, unless perhaps we use the most powerful induction coils—there is the same magnificent order, though it may not be fully known, which exists throughout nature, and we find hydrogen thinning out at one level and magnesium thinning out at another, and so on; and I have suggested that the system of strata produced by this thinning out may be connected with the true vapour densities of the elementary bodies.

With regard to magnesium and calcium, I should remark that the list, made in 1874 will most probably have to be revised, as one of the results of the Eclipse Expedition to Siam in 1875;[1] for although in all past work on the sun it was impossible to determine whether magnesium or calcium was highest, the Siam observations seem to add to the probability that calcium really lies above magnesium; in other words, that the true vapour density of calcium is less than the true vapour density of magnesium. This reference to vapour densities will in the next lecture bring me into complete *rapport* with Professor Roscoe's lectures on the chemical structure of the earth's crust.

THE PLANETS.

There is still, however, another large group of bodies to be considered—I refer to the Planets—before we have exhausted the bodies external to the Earth. Although, however, this group of bodies is numerous, we have not very much to say about them, for a reason which I am sure you will easily appreciate. When we deal with the radiation of the heavenly bodies, we are dealing with a condition of vibration of particles of those bodies at their utmost fineness, so that each vibration comes to us with a story to tell as to the actual chemical constitution of that body. Then when we come to that large class of objects which we study by means of absorption, there again we have the same molecules doing the same thing, but instead of giving us vibrations of their own, they absorb other vibrations which were attempting to pass through them. But when we come to the planets, we come to bodies like our own earth; bodies comparatively cool; bodies not in a state of incandescence, where matter is not as a rule in a state of gas or vapour, but

[1] I have done this in the table as given.

in the solid form. We come therefore to bodies which can neither radiate nor absorb light, in the sense in which we have dealt with radiation and absorption; because, in consequence of the reduction of their temperatures the chemical elements have compounded; we have not the individuality which is requisite; we have not the discrete particles, but combinations of every complexity. As the result of that, what is our only chance of seeing them at all? We see them by reflected light. The bodies now under consideration, unlike the nebulæ and comets, and unlike the stars, reflect light to us, and only by the reflection from their surfaces can we tell that they exist. Now as all bodies, whether they are solid or liquid, are spectroscopically dead, so to speak, so far as getting chemical information from them is concerned, inquiry is perfectly useless excepting in one particular—it proves that it is powerless, by showing that the light of the sun is so faithfully reflected by these bodies, that all the principal lines of the solar spectrum are to be found in it. It is true that there are exceptions in the case of the exterior planets of our system, especially in Uranus and Neptune. In the spectrum of those bodies, cool though they are, like our own, in addition to a constant absorption of the sun's atmosphere and the earth's atmosphere, a third absorption of the atmosphere of the individual planet is indicated. With that exception, you will see that the spectroscope is powerless to help us. How then can we hope to get at the chemical constitution of the planets if the spectroscope does not come to our assistance? There is, I fear, only one chance for us, and that is to determine, as nearly as may be, the densities of these bodies, and to see if it is possible to find out anything to reason upon when these densities have been thoroughly well sifted. Now we do know already with some accuracy the density of the planets. We know that these planets may be broadly divided into two groups; we have the interior group, of which the Earth is one—Mercury, Venus, the Earth, Mars—small heavy planets. The density of the earth is about five and a half times the density of water. The density of these interior planets you may say, roughly, is the same as the density of the earth; therefore we have this group of interior planets with a density of five and a half times that of water. After this we have a considerable gap, a gap partly filled by the minor planets or asteroids; and after that we get another group—Jupiter, Saturn, Uranus, Neptune —not small and dense planets like the Earth, but enormous

light planets, having, roughly speaking, and on the average, about the density of water. So that the density of the interior planets is to the density of the exterior planets about as five to one. Now if this density were known to be associated, in the case of the planets I have named with equal solidity from centre to circumference, of course we should be able then to form a rough idea as to their composition. But we do not know that. But still let us, if we can, carry the inquiry into the secondary bodies of this system—into their satellites.

If we take the only case in which facts approximately accurate are at our disposal—the case of Jupiter—we find that if we take the density of the satellites of Jupiter to be on an average one, the density of Jupiter is five, and the density of the Earth as an interior planet would be twenty-five ; so that the outside planets of our system are one-fifth the density of the inside planets ; and in the only case where we have a complicated system of satellites, that we can deal with, we have exactly the same relationship there, and the satellite is only one-fifth of the density of the planet itself.

I hope to have the opportunity next week of pointing these remarks by reference to what I have already brought before you, especially to the condensation of the nebulæ and to the particular position which each chemical element occupies at the present moment in the atmosphere of the sun.

WHY THE EARTH'S CHEMISTRY IS AS IT IS.

LECTURE III.

In the latter part of the last lecture I referred to the different densities of the two great planetary groups. We saw the interior group of a density, roughly speaking, five times greater than that of the exterior group; and taking the satellites of one body in the exterior group, we found the same relationship of density; the primary being five times as dense as the secondary body, which in that case was one of the satellites of Jupiter.

Now the fact that the Earth is one of the interior group of planets leads us to assume (and I pointed out to you that assumption is almost the only thing left to us in regard to estimating the chemical relationships of the earth) that probably the chemical constitution of the earth is similar to that of the planets which form the interior group—Mercury, Venus, the Earth, and Mars. Now if we look upon the planets from another point of view, if we consider the extent to which some of them are flattened at the poles, we find the same grouping as we did before. The interior planets are flattened very little at the poles, as compared with the flattening of the exterior bodies. Now this flattening has been very beautifully experimented upon by Professor Plateau; and, thanks to Mr. Binyon's skill, I hope I shall be able to throw on the screen some of the phenomena to which Professor Plateau refers. When it is a question of investigating the flattening of a planet experimentally, the first thing one has to do is to take away the influence that gravity might have on the body experimented upon; and Professor Plateau very ingeniously did this by making the rotating body a mass of oil in a mixture of spirit and water of precisely the same specific gravity; so that the mass of oil in the centre was neither inclined to rise nor fall, if the mixture had been

properly made. Here we have on the screen an image of such a mass of oil and a disc connected with a spindle, which we can cause to revolve somewhat rapidly. The revolution of the spindle is communicated to the oil by means of the disc, and what we find is this (supposing the experiment to be perfect). With a certain amount of rotation, the spherical form of the oil first changes into a spheroidal one; as the rotation is increased we get a flattening—as the mass of oil is compressed in one direction it is extended in the other—and we get the equivalent of what we have in the Earth which we describe by saying that the equatorial diameter is so much greater than the polar diameter. When we are able to repeat this beautiful experiment under the best conditions, we find that after a certain point, the oil is not content with expanding in one plane; it is not a question of shortening one diameter and increasing another, but under one set of conditions the oil can be made to form a complete ring, absolutely perfect and disconnected from the central disc; and when the rotation of the central disc is slackened, the oil then comes back again and re-forms, so to speak, a miniature planet. That is one case. Another case can be studied by commencing the rotation with somewhat greater rapidity; and what happens then is that, instead of getting the formation of a ring, the oil is broken up and thrown off in tangents, forming a kind of spiral. Those are the two main classes of phenomena which can be observed in this way.

The interior group of planets has a day almost entirely the same as ours—a period of rotation of about twenty-four hours. The period of rotation of the exterior planets has not been determined in the case of the two exterior ones, Neptune and Uranus; but we do know that in the case of Jupiter and Saturn the rotation is accomplished in less than half the time taken by the members of the interior group.

What, then, are the facts with regard to these planets and their flattening? I am able, by the kindness of several friends, to throw upon the screen some very beautiful drawings of all the planets which I have mentioned; and I want you to be good enough to look at these drawings from two or three points of view. First, I want you to see the difference in the amount of the polar compression in each case; and, for future reference, also the difference in the atmospheric effects. We will begin then with the planet which is most similar to our own, the planet Mars.

You will see that it has markings similar in kind, no doubt,



FIG 19.—Mars; south pole visible.

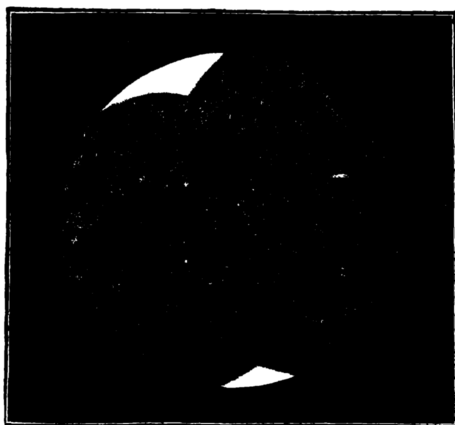


FIG. 20.—Mars, both polar caps visible

to the markings which would be seen by the spectator observ-

ing the Earth from the Moon. You will see also that its compression is small—in fact, I may say, that it is not to be appreciated at all. Here are three drawings of Mars, made by the distinguished Dutch astronomer, Kaiser, of Leyden. You see that there is no polar flattening. That the upper part represents the true pole of the planet is rendered evident by the fact that you have there a snow cap at the south pole. There again you have the snow cap; and here in these dark markings we have seas. The Earth's place then, in Nature, both as to polar compression and atmospheric condition, is evidently very similar to that of Mars. When, however, we go



Fig. 21.—Jupiter.

from Mars, which is the only member of the interior group, excepting the Earth, about which we can say anything with decision, we see that all the phenomena are considerably changed. We pass from a density of five to a density of one, and the twenty-four hours day or thereabouts of Mars is now replaced by a day of something like ten hours in the case of Jupiter, the planet which comes next in our survey. Here we see how much shorter the polar diameter is than the equatorial one. You will be reminded by these cloud-belts of the much more simple system of cloud-belts which traverses our own Earth near the equatorial regions. There is little

doubt that the darker portions here are the portions of the atmosphere of the planet freest from cloud, and it is especially in this region that an observation to which I shall presently have to refer was made. Going then still outwards, we come from a compression of considerable magnitude to a planet in which the compression is somewhat less. But you will see, that although the polar compression is somewhat less, we have what I termed an "extreme case," when I was referring to Plateau's experiment. We have in the planet before you (Saturn) exactly the condition which was observed by Plateau in his experiments with the oil and mixture of spirit and water. We have traces of clouds, as in Jupiter; but the all-absorbing feature in the case of Saturn is this wonderful ring, about which observations are, fortunately for science, being very rapidly accumulated, showing that considerable changes are going on in it.

We now know that we are in presence of a ring, or rather an infinite series of rings, of, let us say, meteorites, small satellites of Saturn, out of which at some future time larger satellites will be compounded. This is one of the most beautiful results of modern thought and work. Laplace, who first considered the question of the mechanics of the rings, which were in his time considered to be solid, was content to leave them solid, provided the rings were very numerous and that the centre of gravity of each was not coincident with the centre of gravity of the ball; but modern mathematicians, among whom must be specially mentioned Peirce and Clerk Maxwell, have shown that the rings cannot be solid and cannot be liquid, and in short such a structure as that referred to above is the one now required by mathematical theory. Such a structure, moreover, is the only one which fits the facts. The brightness of different portions, the variations in brightness and breadth of each bright or dark part, the gradual widening of the whole system—29 miles a year according to one estimate—and many other facts are thus easily explained. Some recent observations[1] made by the Washington 26-inch equatorial not only establish important changes which have recently been going on, but afford further evidence of the meteoric structure of the strange appendages, *e.g.*, the dusky inner ring is not now perfectly transparent as it once was, the planet can only be partly seen through it, while the matter composing it is agglomerated here and there into small masses, which prevent the planet being seen. Mottled

[1] Trouvelot, Proc. Amer. Acad. 1876, p. 174.

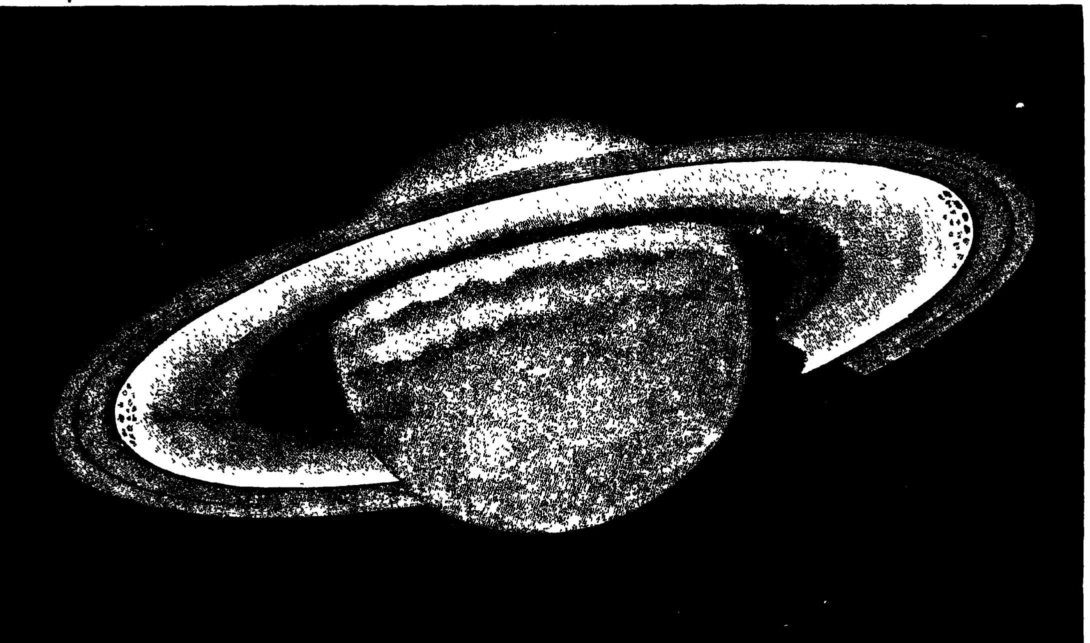


Fig. 22.—Saturn, from a drawing by Trouvelot, made by the Washington 26-inch refractor.

or cloudy appearances have also been observed on the surface of the exterior portions of the ring system during the last four years.

We must now pass from the facts relating to the physical condition of the two great groups, as it is as yet impossible by a further discussion of them to learn anything about the chemical constitution of the planets themselves. The question arises—Can we learn anything about the composition of their atmospheres? Let me remind you that we are dealing with that class of bodies which shine by reflected light. It is clear therefore that when we examine by the spectroscope the light of the sun reflected by these bodies, we shall have the solar spectrum, *plus* the spectrum due to the absorption of any special planet. Now, as a matter of fact, the solar spectrum, as observed from the Earth, is tainted by, or mixed up with, the absorption of our own atmosphere. But fortunately we can get rid of the absorption effect of our atmosphere by varying the observations so that at one time we shall have a great thickness of atmosphere, as when we observe the sun in the morning or evening, and at other times a small thickness, as when we observe at mid day; and at those times we shall have the spectrum changed, owing to this change of condition. In that way men of science have been able to separate the absorption taking place at the sun, from the absorption due to the Earth's atmosphere.

The interior planets tell us that there is absolutely no special absorption in their atmospheres. So far as they have atmospheres at all, they are undoubtedly similar to our own; therefore the Earth's place in Nature is with the interior groups of planets. But when we pass outwards from the interior group to the uttermost confines of the exterior one, when we leave Mars to go to Neptune, Saturn, and Uranus, we find that from Jupiter, outwards, there is a something interpolated into the atmosphere, so that the outermost planet has the atmosphere, which differs most from our own. Uranus and Neptune have very extraordinary atmospheres of their own, which are indicated by a very definite spectrum. Traces of the substance which gives us this extraordinary absorption in the outermost planets are also to be found in the atmospheres of Jupiter and Saturn; so that we are driven to the conclusion that the atmosphere of the exterior planets is different from the atmosphere of the Earth by the addition of a new absorbing substance to the aqueous vapour which is the only *effective* absorber in our own atmosphere.

THE QUESTION OF EVOLUTION.

I have now gone through, *seriatim*, the physical and chemical constitution of nebulæ, stars and planets, so far as the facts and the time at my disposal have enabled me. What may we say then as a general summation of these facts, brought together with a view of determining whether they throw any light on the cause of the Earth's actual chemical constitution? Physically speaking, the Earth is a cooled body, revolving round an incandescent one. Chemically speaking, its chemistry has been most admirably brought before you by Dr. Roscoe in those three lectures which we have now the opportunity of reading carefully; and its kinship with the other bodies which people space has been established by the fact of the community of elements. Dealing only with the spectra which have been observed in the nebulæ we have recognized hydrogen; in the comets we have recognized hydrocarbons; in the stars and in the sun we can tell of elements amounting to twenty-five in the case of the sun, nearly all of which elements we have on this Earth; so that it is not too much to say that one of the glories of the spectroscope has been to show that the Earth in its chemical constitution is simply a part of one of the great systems of the universe, and differs in no way from the matter which masses here as nebulæ, there as comets, and there as stars.

I have drawn your attention to the conclusions which we are justified in drawing from the facts; and the question is, Does the story end now the facts end? I hope to show you that it need not necessarily do so. A student of science endeavours to accumulate facts. Facts are the rewards of scientific work; but how, when a man of science has accumulated a large number of facts, is he best to proceed to get new ones? That is our case. I have endeavoured to bring before you all the facts, roughly, which the spectroscope has placed at our disposal with regard to the chemical constitution of those different masses of matter which people space. But how are we to attempt to get more? Are we to go haphazard at it? No. Hypothesis is the life-blood of investigation; and having an array of facts before you, the thing to do is to attempt to put them in such an order that they will suggest inquiry in special directions. Do not be afraid when I say that hypothesis is the life-blood of investigation, lest the world should

soon be filled with hypotheses. History does not bear this out; and further, a man does just as good work by destroying an unsound hypothesis as by establishing firmly a true one. Having then these facts before us, and having necessarily to form some hypotheses, what is the most general question that we can put to these facts, which tell us of the existence of nebulæ, comets, suns, planets, and the like? The most general question, I think, that we can ask is such a one as this: Have we, as the result of our inquiry, got together such facts as enable us to consider nebulæ, stars, comets, and planets as finished products, each of them gloriously, magnificently, perfect in its way; or do these merely represent, let us say, the seed and the flower and the fruit?

Here, of course, we have to do with Evolution pure and simple; and I may remind you that it is now a good many years since two of the most profound thinkers on our planet at the time—I refer to the German and Frenchman, Kant and Laplace—independently arrived at the answer to the question I have propounded. The answer was identical, and it was this: You have in these various bodies not finished products, each perfect after its kind, but really and truly the seed and the flower and the fruit. And the hypothesis which they put forward was something like this—that the nebulæ, representing what I told you Tycho Brahe considered them to be—a true fire dust—was probably wrought into stars by means of the condensation due to gravity, which in time brought the most irregular nebulæ down to the appearance and the consistence of a star. And then Laplace and Kant, knowing well of the observations of the rings of Saturn—the experimental imitation of which I have brought before you—suggested that our planets were left behind, first as rings, while the nebula was contracting to form a star. So that if you begin, in any quarter of space that you choose, with a nebula, and give it time to work, the nebula will condense, a star will be formed, and in the process rings, which will subsequently break up and form planets which will subsequently cool, will be produced. Such then is an hypothesis which has now been before the world some years and certainly is exceeded by none in the grandeur and grasp of its conception; it was started before the spectroscope, as we now know it, was dreamt of. Do the facts which have been brought to light by the spectroscope lead us to think that this hypothesis will no longer hold water now we have got a larger area of facts to deal with or do the new facts really

come well in and support the old and enable us to fit other parts into it?

Now, in order to deal with this question, I shall first trace the passage from the nebula to the star, which is the first part of the conception of Kant and Laplace. If you will consider the conditions at work in a nebula such as I told you Professor Tait is content to imagine it, namely, a nebula consisting of a huge cloud of stones. the luminosity of which depends chiefly upon the impact of these stones together, and I suggest in part upon dissociation of hydrocarbon—if you take such a nebula as this, and imagine it to be condensed to a star, you will see at once that the conditions of Plateau's famous experiment are exactly reversed. In the experiment, we begin with the star at rest, and the experiment is performed by setting it in motion. But in truth, if Kant was right, that experiment must be exactly reversed; rotation will be at the end of the business. We must imagine rotation set up over an immense area, rapid enough, after the condensation in a plane is considerable, to give us many rings. What Plateau saw when the matter went outwards will occur backwards, as the matter condenses inwards. Instead of rings formed and moving outwards we shall have rings formed and moving inwards, tangential outpourings will be represented by tangential inpourings. I will recall your attention to two or three nebulæ, which I showed you on a former occasion, and in the light of this hypothesis, I think you will see that the telescopic evidence is also in favour of the idea. I am now about to show you the group of nebulæ sketched by Lord Rosse, some of them having been observed in the first instance by Sir John Herschel. I do not wish to call your attention to all of them, although much might be said, I am sure, about every one; but I want especially to draw your attention to those which resemble Saturn, and are like the sphere and ring of oil in Plateau's experiment. We have in the centre a condensation; we have around it a globular mass not so brilliantly illuminated: and around it again we have a ring. There again is an object of an almost similar kind, seen from a different point of view, in which the ring is edgeways to us. I might go on taking up very much more of your time, but I don't think it is necessary to enlarge very much upon this part of the subject, after the drawings I showed you on the first occasion. It will be clear to you that

if we take this view we shall demand with each degree of condensation, with each degree of contraction, an increase in brilliancy; so that the smaller the space occupied by the materials which first constituted the nebula, the brighter and the hotter will they become. So that we must imagine that the star finally formed must be one in an intense state of incandescence; in fact, in a state of incandescence of which we cannot have the most remote notion.

What says the spectroscope? Here the spectroscope is quite at one, I think, with the idea; in fact, there are nebulæ and stars with spectra so similar that if one had the evidence of the spectroscope alone, it might be impossible to decide which was nebula and which was star. Now this may be a little startling to some of you, and therefore it is only fair I should explain it. The stars, you know, are so remote from us that in the most powerful telescopes to which spectroscopes are applied, they appear only as the finest points of light. Now these points of light, it is not absurd to imagine, may in some instances be two millions, or perhaps even three millions, of miles in real diameter. We know that our own sun, which is certainly not the largest star in the heavens, is nearly one million miles in diameter; that is to say, the true sun, the true stellar nucleus, is one million miles in diameter. Now when I dealt in my second lecture with the physical constitution of the sun, I pointed out that the sun which we see, the sun which sends us the majority of the light we receive, is but a small kernel in a gigantic nut, so that the diameter of the real sun may be, say, two million miles. Suppose then that some stars have very large coronal atmospheres; if the area of the coronal atmosphere is small compared with the area of the section of the true disc of the sun, of course we shall get an ordinary spectrum of the star; that is to say, we shall get the indications of absorption which make us class the stars apart; we shall get a continuous spectrum barred by dark lines. But suppose that the area of the coronal atmosphere is something very considerable indeed, let us assume that it has an area, say fifty times greater than the section of the corona of the star itself; now, although each unit of surface of that coronal atmosphere may be much less luminous than an equal unit of surface of the true star at the centre, yet if the area be very large, the spectroscopic writing of that large area will become visible side by side with the dark lines due to the

brilliant region in the centre where we can study absorption; other lines (bright ones) proceeding from the exterior portion of that star will be visible in the spectrum of the apparent *point* we call a star. Now it is difficult to say whether such a body as that is a star or a nebula. We may look upon it as a nebula in a certain stage of condensation; we may look upon it as a star at a certain stage of growth.

And in the fact that we have actual nebulous stars—stars which in the telescope can scarcely be defined from true stars, and spectroscopic effects such that it is difficult for us to say whether they are produced by star or nebula, we have in these two points very strong arguments indeed in favour of this part at all events of the evolution hypothesis.

So much then for the passage from nebula to star. How about the passage from star to planet? Let us, in the first instance, assume that the nebula is vastly condensed before the rings begin to form. It is difficult of course for us to say whether this is really true or not, because we know not the distance of the nebulæ; but I think you will agree that it is a fair assumption. In this case, if the condensation is excessive, and the heat due to arrested motion be excessive also, we shall have then to deal with the facts. Where in the heavens have we just this particular series of facts? We have it in the sun. We have the sun now near to us, so that we can study its constitution, still in a state of intense incandescence, and so far as that point goes at all events it may be fairly taken its represent probably an earlier stage of its growth. And the being so, I think it will be fair to take the sun as representing the closest approximation to a nebula in its last stage which is available to us. It would be better perhaps if the line between the inner and outer atmospheres were less sharp, but we must take it as it is. Now one of the most unforeseen results connected with recent solar work has been that the different chemical substances which various observers have placed in the atmosphere of the sun, are not all mixed up pell-mell, but are really thinned out into layers; so that we can not only say, when we wish to compare the chemical constitution of the Earth with the sun, that the chemical constitution of the sun is so and so, but we can say that in the chemical constitution of the sun this element occupies one position in the solar atmosphere, and that element occupies another. So that, in fact, taking the sun to represent a nebula at the time

that rings were being formed (mind you, I don't say thrown off, we must reverse Plateau's idea), the fundamental point we have to bear in mind is that if we take the sun at all, we must take it with its layers. Now here we have an opportunity which Kant had not; and here, I think, the spectroscope enables us to deal with Kant's hypothesis in a somewhat satisfactory manner. We may be said to improve somewhat upon the conceptions which were merely physical by making them slightly chemical. Now if we have these known metals placed as near as may be in this order [Table]—probably the position of the metal aluminium is the most doubtful,—we have in the first instance to account for the absence of the metalloids. I have given grounds elsewhere, and it is not necessary to repeat them to-night, for believing that the most probable position for the various metalloids in the solar economy is outside these metallic strata. So that if we take a section of the sun's atmosphere, we must imagine the metalloids to be outside if they be there at all, and then as a link between the metalloids and denser metals, hydrogen, calcium, and magnesium generally coming in that order, or thereabouts. Let us for a moment consider the sun as a nebula. There is ample evidence, I think, to show that the temperature of the nebula was then as great as the temperature of the sun is now; consequently you will have all these metals existing uncombined, the metalloids existing outside, also probably uncombined. And what happens on Kant's hypothesis?—that the nebula in starting a rotation and contracting leaves behind it its exterior portion; so that probably we may say that the first planet thrown off—let us assume that that was Neptune, although probably there are many planets beyond Neptune—must have been thrown off from the extreme limit of such a nebula, and must have been built up of those particular materials which were existing at that particular part of the nebula; *that is to say, that it is almost impossible that there should not be an overwhelming preponderance of metalloid in Neptune.* As the various rings are formed from the exterior of the nebula while the contraction is going on, they will consist chiefly of metalloids; whereas when we come nearer to the sun, they will consist chiefly of metal. Now that being so, we have two opportunities of testing the idea which has led to this conclusion. If the exterior planets are metalloidal and the interior planets are metallic—(I do not mean that one group is *entirely* metal-

loidal and another *entirely* metallic)—it will be impossible for the density of the exterior planets to be as great as the density of the interior planets. We have already found out that that density, as a matter of fact, is about one to five. This density, of course, must be lower, because we shall have the best possible conditions for high density where we get the metal in its purest state. Where the density then is least, in the case of the exterior planets, we shall find probably that the velocity of rotation will be different from the velocities of rotation of the other planets. That also, I have already pointed out to you, has been entirely answered by observation. Let us then, if we can, take this one step further. Let us take for granted that the difference between the interior planets and the exterior planets is precisely of this kind. Can we trace the same principle—can we send this chemical touch further into the hypothesis, and deal with, say, no longer the sun and the planet, but a planet and its satellite? I think we can; and I think too that in the case of Jupiter, the density of which as compared with the density of its satellites I have already mentioned to you, we have a most singular corroboration of the continuation of the sifting process.

If the facts I stated in the last lecture were accurate—and I believe they were as accurate as they may be in the present state of science—the density of the satellites of Jupiter in the main is only about one-fifth that of water. Now it so happens that one of the satellites of Jupiter, when it crosses the disc, very often puts on a very dark appearance. We have, therefore, here very good reason to infer that this particular satellite of Jupiter may probably be merely a mass of gas; and it is very possible that in the case of Neptune and Uranus we may be dealing with bodies which, for the same reason, will remain almost for ever in a semi-gaseous state. And let me remind you that this would at once explain the spectroscopic researches of Vogel and others on the atmospheres of these planets. If you have an atmosphere round Neptune and Uranus consisting of combined metalloids, we may have our choice between several possible spectra. I believe no one has yet made the direct experiment, but the description of the spectrum of Neptune given by Vogel is not very dissimilar from the spectra of the different oxides of nitrogen. That at once then would

explain the various spectroscopic differences as well as the compression difference.

I must remind you, in order to make perfectly clear what I have already ventured to bring before you with regard to the form of these rings, that of course it is assumed that after the ring has been formed it eventually breaks up. Now the facts, I think, seem to show that when this breaking-up takes place, a considerable amount of heat is produced; so that you see, if we consider the density of the exterior planets and their satellites, Jupiter, &c., and of our own Earth and its satellite, we have indications not only that this sifting, this sorting process, did really go on in the formation of the satellites as well as in the formation of the primaries, *but, because this process could go on at all, we have, I think, also additional evidence that there must have been a great amount of heat produced.* This heat is necessary to the hypothesis, both for the formation of the primary and the secondary bodies; because, unless you have heat enough to get perfect dissociation, you will not have that sorting out which always seems to follow the same law.

So much then for the passage from star to planet. Does this then throw any light upon the question—what I acknowledge to be one of the great points it is my duty to discuss—of the origin of the chemical constitution of the Earth?

Twice I have insisted upon this—that the hypothesis is almost worthless unless we assume very high temperatures. Now then, let us consider the Earth, which we know to be one of the interior planets, at the moment the ring—in which form it once existed according to the hypothesis—had been broken. By the breaking of this ring we have the future Earth, a mass of vapour in a state of incandescence

I have already told you enough about the near similarity of the chemical constitution of the earth and sun to justify me in again asking you to let me see in the existing sun just such a mass of matter as our Earth then was. Now then, we simply go over the same line of facts again. This list of metals, with the exterior metalloids, must now do duty, not as it did before, for a nebula before it threw off its rings, but for our own Earth, after the time when a ring had formed to become the Moon ultimately. What would happen?

We know for certain that the Earth is now a cool body; but I do not think we know that with any greater certainty than we know that the Earth was once a very hot body; therefore

there has been a process of cooling going on. Now I want you to answer for yourselves this question, What would be the stages of the cooling? We have, by hypothesis, metalloids outside—metalloids not in combination with metals, in consequence of the high temperature. Such as the solar condition is now, such doubtless was the terrestrial condition then. What is the first process then that takes place on cooling?—combination. What then will be the process of combination? The metals and the metalloids will combine, according to their position in the present atmosphere of the sun, in the then atmosphere of the Earth. If, let us say, oxygen and chlorine cannot combine with hydrogen at a particular stage of temperature, they may go lower down, and attempt to combine with calcium and magnesium. But it is certain that if at any time they could have combined with magnesium and calcium, they would have had no chance of combining with iron, because iron was shielded by this enormous buffer of the upper metals. So that we ought to find that the crust of the Earth in the main consists of combinations of metalloids with those metals which exist highest in the atmosphere of the sun. Now it is not necessary that I should state any detailed facts on this point, because Professor Roscoe has already done that for me. I am sure you will all at once grasp that the composition required by the state of things I have pictured is exactly such a composition as Dr. Roscoe has brought before you; and if that is not sufficient I will read this extract from a work by an eminent geologist, Professor Prestwich. This is what he says about the composition of the Earth's crust:—

"The whole number of known elements composing the crust and atmosphere of the Earth amount only to sixty-four, and their relative distribution is vastly disproportionate. It has been estimated that oxygen in combination forms by weight one-half of the Earth's crust; silicon enters for a quarter; then follow aluminium, calcium, magnesium, potassium, sodium, iron, carbon. These nine together have been estimated to constitute $\frac{977}{1000}$ of the Earth's crust. The other $\frac{23}{1000}$ consist of the remaining fifty-five non-metallic and metallic elements."[1]

Now I think that I shall carry you with me when I say that an hypothesis like the one which I have brought before you

[1] Prestwich, *The Past and Future of Geology.* Macmillan, 1875.

—an hypothesis due to Kant and Laplace—which leads to mental results so very near the truth of nature, if it cannot be accepted as actual truth, is so near the truth that it deserves that any amount of trouble shall be brought to bear upon it to test it more and more carefully, to find out its weak points and to promulgate its strong ones, in order to beget thorough work.

You see then that if the metalloids combine with this upper group of metals, two things happen—two points relative to the chemistry of the Earth, which are well worth further inquiry. It follows that a large mass of the interior of the Earth consists of pure metal—and as Dr. Roscoe has referred to that point I need not touch upon it further—and if the Earth is anything like the sun—and we have no reason to doubt their almost perfect similarity—we may be perfectly certain that a large portion of that metal will be iron. It is quite possible that the magnetic state of the Earth—for the Earth is a great magnet—may be connected with the existence of this enormous mass of perfectly pure iron low down in the Earth. I am not recalling your attention to the existence of this pure iron with any commercial view, but it is important that we should learn all we can in regard to the Earth's magnetism, upon which our commerce so largely depends.

Another point is this, if the history of the Earth and the history of the other planets, so far as the chemical nature of the crusts goes, is a history of the descent of the metalloids upon the metals, *we must regard the atmosphere of any planet at any time as the mere residuum which has been left after all possible combination has taken place.* Our own atmosphere consists of oxygen and nitrogen—still uncombined, fortunately—and of aqueous vapour, a combination of oxygen with the highest known metal which we see on the list.

This consideration at once explains how it is that in the moon—which at one time doubtless was the scene of activities of a geological character probably far greater than anything which took place here; that in the moon—of which I bring before you a very beautiful portrait by Mr. Rutherfurd, of New York—so far as we know, there is now no atmosphere at all; or, at all events, if any atmosphere exist there, it is one so slight that scarcely a remnant of the pure gases has been left, and no aqueous vapour.

This brings us to several very interesting questions regarding the Earth's future: but I feel that I shall not be justified in entering upon them. I trust, however, with regard to the past, that you will be content to see, in the facts that I have ventured to bring before you, that chemists really would be justified in giving great attention to the study of the chemical nature of non-terrestrial matter, in order that the true chemistry of the Earth may be better understood.

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